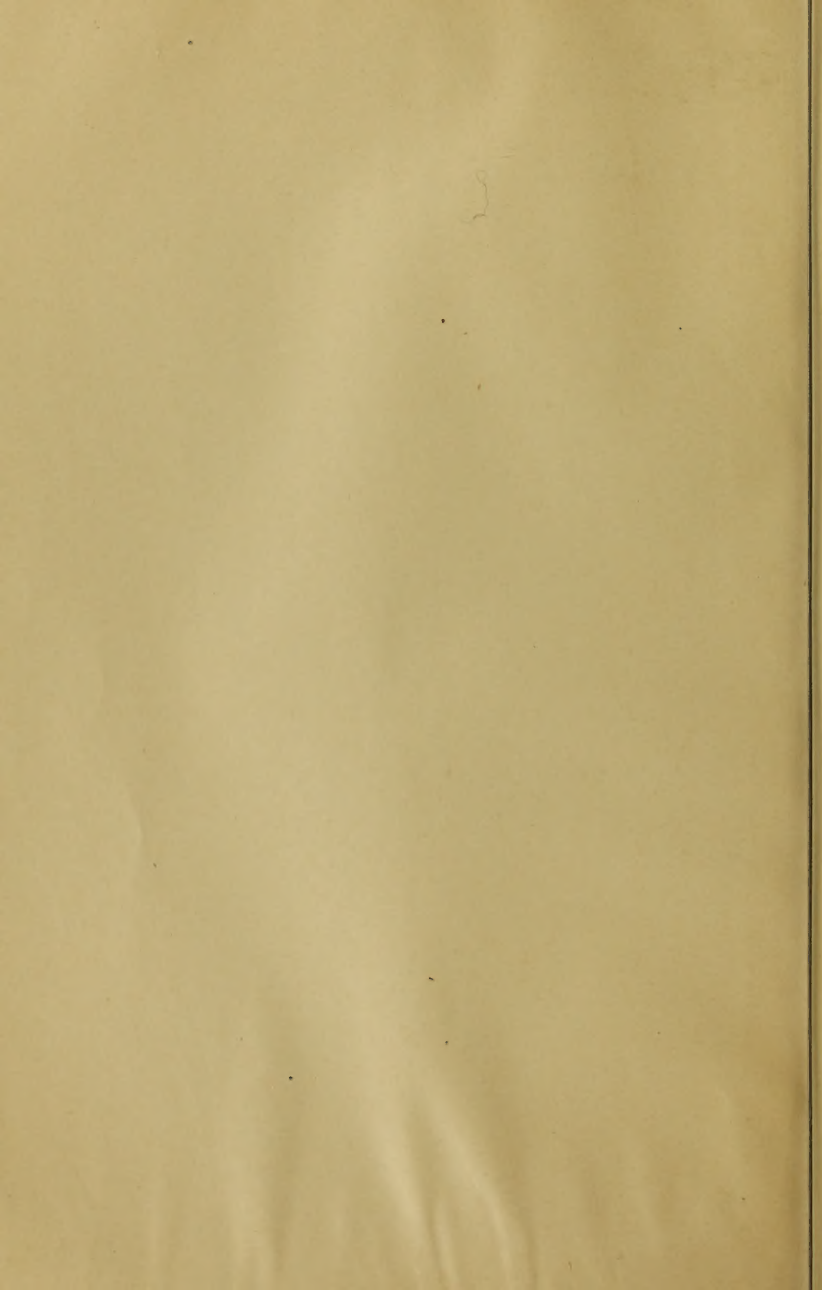


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ANNUAL REPORTS

OF THE

DEPARTMENT OF THE INTERIOR

FOR THE

FISCAL YEAR ENDED JUNE 30, 1900.

TWENTY-FIRST ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY,

CHARLES D. WALCOTT, DIRECTOR.

PART II.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1900.

TWENTY-FIRST ANNUAL REPORT
OF THE
UNITED STATES GEOLOGICAL SURVEY

PART II.—GENERAL GEOLOGY, ECONOMIC GEOLOGY, ALASKA

CONTENTS.

	Page.
CROSS, W., AND SPENCER, A. C. Geology of the Rico Mountains, Colorado (Pls. I-XXII)	7
MATTHES, F. E. Glacial sculpture of the Bighorn Mountains, Wyoming (Pl. XXIII)	167
TURNER, H. W., KNOWLTON, F. H., AND LUCAS, F. A. The Esmeralda formation, a fresh-water lake deposit, by Mr. Turner; accompanied by a report on the fossil plants of the formation, by Mr. Knowlton, and by a report on a fossil fish, by Mr. Lucas (Pls. XXIV-XXXI)	191
WEED, W. H. Mineral vein formation at Boulder Hot Springs, Montana (Pls. XXXII-XXXIV)	227
TAFF, J. A., AND ADAMS, G. I. Geology of the eastern Choctaw coal field, Indian Territory (Pls. XXXV-XXXVII)	257
TAFF, J. A. Preliminary report on the Camden coal field of southwestern Arkansas (Pls. XXXVIII-XXXIX)	313
BROOKS, A. H. A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits of the upper White and Tanana rivers (Pls. XL-L)	331
ROHN, O. A reconnaissance of the Chitina River and the Skolai Mountains, Alaska (Pls. LI-LIX)	393
SCHRADER, F. C. Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899 (Pls. LX-LXVIII)	441
BAKER, M. Alaskan geographic names	487
INDEX	511

GEOLOGY OF THE RICO MOUNTAINS, COLORADO

BY

WHITMAN CROSS and ARTHUR COE SPENCER

CONTENTS.

	Page.
PREFACE, by Whitman Cross	15
CHAPTER I. Outline of the geology, by Whitman Cross	17
Literature concerning the region	17
Hayden Geological Survey	17
John B. Farish	18
T. A. Rickard	18
Telluride and La Plata folios	19
General description of the mountains	19
Physiographic relations of the mountain group	19
Drainage system and vegetation	20
Details of physiography	20
Structure of the Rico Mountains	21
Elements of the structure	21
Rico dome	22
Relation to the San Juan structure	23
Relation of faults to the dome structure	23
Relation of intrusive rocks to the dome structure	24
Stratigraphy	25
Sedimentary section represented	25
Algonkian rocks	26
Devonian	26
Carboniferous	27
Permo-Carboniferous	27
Juratrias	28
Igneous intrusions	29
Intrusive sheets	29
Cross-cutting stocks	30
Later dike rocks	31
Contact metamorphism	32
Volcanic phenomena	32
Solfataric action	32
Existing sulphur springs	33
Carbonic acid exhalations	33
Ore deposition	33
Erosion of the Rico dome	34
Recent geologic history	35
CHAPTER II. The sedimentary formations, by Arthur Coe Spencer	37
Algonkian	37
Introductory statement	37
Relations of the Rico Algonkian	38
Description of the quartzites	39
Description of the schists	39
Occurrences	40

CHAPTER II. The sedimentary formations—Continued.	Page.
Devonian.....	41
General relations.....	41
The quartzite.....	43
The limestone.....	45
Economic importance of the limestone.....	47
Carboniferous.....	47
Hermosa formation.....	48
Characteristics in the San Juan region.....	48
Definition.....	48
General description.....	48
Animas section.....	48
Description and division of the Rico section.....	49
General statement.....	49
Lower division.....	50
Exposures of the lower beds.....	50
Medial division.....	53
Upper division.....	57
Fossils and correlation.....	59
Rico formation.....	59
Definition.....	59
Discovery of the formation.....	60
Description.....	60
Local distribution.....	62
Correlation.....	64
Juratrias.....	66
Introductory.....	66
Dolores formation.....	67
Definition.....	67
General description and subdivision.....	67
Lower, unfossiliferous division.....	68
Upper, fossiliferous division.....	71
Distribution and occurrence.....	72
La Plata formation.....	73
Definition.....	73
Description.....	74
Distribution and occurrence.....	75
Correlation.....	76
McElmo formation.....	76
Definition.....	76
Description and occurrence.....	76
Correlation.....	77
Cretaceous.....	77
CHAPTER III. The igneous rocks and their occurrence, by Whitman Cross...	79
Petrography.....	79
Monzonite.....	79
General description.....	79
Variations of the monzonite.....	81
Relations to other occurrences.....	81
Porphyries associated with the monzonite.....	83
Hornblendic monzonite-porphyry.....	83
General description.....	83
Decomposition products.....	85
Relationships of this porphyry.....	85
Porphyry of Calico Peak and vicinity.....	87
Basic dike rocks.....	87

CHAPTER III. The igneous rocks and their occurrence—Continued.	Page.
Phenomena of intrusion	88
Porphyry masses	88
Centers of eruption	88
Stratigraphic distribution of sheets	90
Small dikes	90
Monzonite stock	91
Form and dimensions	91
Relation to porphyry sheets	91
Phenomena connected with igneous intrusion	91
Contact metamorphism	91
Solfataric action	92
Comparison of the Rico Mountains with laccolithic centers of eruption	94
The laccolithic mountain groups	94
Stocks and laccoliths of the Telluride quadrangle	96
Relations of the Rico Mountains	96
CHAPTER IV. Structure of the Rico dome, by Whitman Cross and Arthur Coe	
Spencer	98
Introduction	98
The broad San Juan structure	99
San Juan dome	99
Rico and La Plata domes	100
Relation of local domes to larger structure	100
Structure of the Rico dome	101
Elements of the structure	101
Profile sections	102
Amount of deformation by folding	103
Uplift due to intrusive porphyries	104
Deformation by faulting	105
Bedding faults	107
Quotation from Farish	108
Description of the "contact" by Rickard	108
Comment upon the quotations	109
Origin of the bedding faults	110
Origin of the dome	112
Description of the faults	114
Spruce Gulch fault	114
Deadwood fault	114
Faults of Dolores Mountain and vicinity	115
Blackhawk fault	116
Nellie Bly fault	118
Last Chance fault	119
Smelter fault	120
Cross faults between Smelter and Last Chance faults	122
South Park fault	122
Area between the Smelter fault and Silver Creek	123
Silver Creek fault	124
Faults bounding the quartzite mass south of Silver Creek	125
Telescope Mountain fault	126
Faults of C. H. C. Hill	128
Other faults	128
CHAPTER V. Landslides, by Whitman Cross	129
General statement	129
Enumeration of landslide areas	130

CHAPTER V. Landslides—Continued.	Page.
North side of Horse Gulch	130
South side of Horse Gulch and Darling Ridge	132
Crest of Darling Ridge.....	132
Physiography of the slope	133
Landslide block at the Puzzle mine.....	134
"The Blowout"	135
Western limit of the landslides.....	136
Telescope Mountain and C. H. C. Hill.....	136
Telescope Mountain	136
C. H. C. Hill	137
Damming of Dolores River.....	138
Recent slipping in C. H. C. Hill.....	139
Magnitude of the landslide action	140
Ridge between Burnett and Sulphur creeks	141
Landslip Mountain	143
Dolores Mountain and Newman Hill.....	143
Region south of Blackhawk Peak.....	144
Discussion of landslide phenomena	145
Distribution of the landslides.....	145
Character of the landslides.....	146
Relations to topography	146
Relations to other Pleistocene phenomena	147
Age of the landslides	147
Relation to faults.....	148
Origin of the landslides	149
CHAPTER VI. Erosion of the Rico dome and recent geologic history, by Arthur Coe Spencer	152
Erosion of the dome.....	152
General statement.....	152
Pre-Glacial erosion	154
Glaciation of the Rico Mountains.....	156
Forms of evidence.....	156
Topographic evidence.....	156
Glacial débris	157
Recent geologic history	160
Post-Glacial erosion	160
Varieties of surface deposits.....	160
Landslides.....	161
Talus	161
Surface wash.....	161
Valley deposits.....	162
Alluvial fans	162
Calcareous spring deposits	163
Ferruginous deposits.....	164
Gas springs	165

ILLUSTRATIONS.

	Page.
PLATE I. View from Blackhawk Peak, looking northeast toward the San Juan Mountains.....	18
II. View looking east from the divide at the head of McJunkin Creek..	20
III. View looking east across the Dolores Valley from the ridge north-east of Burnett Gulch	22
IV. Blackhawk Peak and adjacent summits, from Telescope Mountain..	24
V. Dolores Mountain and Newman Hill, from the west side of the river near Iron Creek.....	26
VI. Sandstone Mountain, from the foot of C. H. C. Hill	28
VII. Calico Peak from the south	32
VIII. Profile sections through the Rico dome	102
IX. Looking up Horse Gulch from Sandstone Mountain.....	128
X. Darling Ridge, from Sandstone Mountain	130
XI. Landslide area on the north side of Horse Gulch, as seen from a point west of the "Blowout"	132
XII. Details of landslide topography in the area on the north side of Horse Gulch.....	134
XIII. A landslide trench on the south slope of Horse Gulch	136
XIV. Landslide bench at the Puzzle mine, in Horse Gulch	138
XV. Telescope Mountain and C. H. C. Hill, from Sandstone Mountain ...	140
XVI. C. H. C. Hill, from near the mouth of Marguerite Gulch.....	142
XVII. Landslide sink on C. H. C. Hill.....	144
XVIII. Tree split by recent landslide movement, upper limit of C. H. C. Hill.	146
XIX. View looking down the landslide ridge southeast from Expectation Mountain	148
XX. South face of Landslip Mountain.....	150
XXI. Alluvial fan at the mouth of Aztec Gulch.....	162
XXII. Geologic map of the Rico Mountains, Colorado	Pocket.

GEOLOGY OF THE RICO MOUNTAINS, COLORADO.

By WHITMAN CROSS and ARTHUR COE SPENCER.

P R E F A C E.

By WHITMAN CROSS.

The Rico Mountains, the area discussed in the accompanying report, are situated in southwestern Colorado near the headwaters of the Dolores River. The summits of this compact and rather isolated group lie within an oval area about 7 miles in diameter from east to west and 5 miles from north to south. Some 8 miles to the northeast is the southwestern front of the San Juan Mountains, and about 16 miles to the south rise the northern slopes of the La Plata Mountains. The peaks are nearly all included within the northeastern section of the Rico quadrangle, but a few lie to the east of the one hundred and eighth meridian, in the Engineer Mountain quadrangle.

The name "Rico Mountains" was first applied to this group of peaks in the course of the work leading to the present report. On the Hayden map of Colorado the term "Bear River Mountains" was used for the same group, but that name has never come into local use, and would now be a misnomer, for it is connected with a nomenclature for important streams which has also failed of acceptance in the settlement of the country since the issue of the Hayden map. On that map the stream now known as the "West Dolores" River was called "North Fork of Rio Dolores;" the main stream, now named the "Dolores River," was designated the "South Fork of Rio Dolores, or Bear River," and from the latter alternative name originated the term applied to the mountains in question. The tributary of the Dolores heading in the La Plata Mountains has long been known as Bear Creek. On the Hayden map it has the name "La Plata Fork."

While the Hayden name for this mountain group has been rejected in local usage the engineers and miners of the region have failed to supply a new one, but the individual character of the group, both geologically and physiographically, makes some name desirable, and that here adopted seems most appropriate. The mining town of Rico is situated in the Dolores Valley, in the heart of the group.

A detailed survey of the Rico Mountains has been made both on account of the economic importance of the district and as a necessity in connection with the areal geological mapping of the San Juan and adjacent mountains, now in progress. In the course of this work the Rico quadrangle was taken up in 1897 and finished, with the exception of the small area about Rico, where the geology was found to be so complicated as to require an accurate and detailed topographical base. It was also seen that an intelligent exploitation of the mineral resources of the district was practically impossible until such a geological map should be available.

In the summer of 1898 the topographical map was made, and on its completion the geological work was at once begun, but could not be finished before the snowfall of early winter. In the season of 1899 the work was completed. During the work of the three years mentioned Mr. Arthur C. Spencer was associated with the writer as assistant geologist. Messrs. Ernest Howe, R. D. George, and Jason Paige served at different times as volunteer aids.

In 1897 Mr. C. W. Purington, assistant geologist, examined the ore deposits of the district, but the determination to make a special map and report rendered it desirable to have a correspondingly detailed study of the economic resources in the following year, and to this duty Mr. George W. Tower, jr., was assigned, as Mr. Purington had meanwhile resigned from the Survey. Before preparing his report upon the Rico district Mr. Tower also left the Survey to engage in private business. As some of the most complicated portions of the region, including the Silver Creek Valley, were not thoroughly understood during Mr. Tower's work, a further study of the ore deposits in the light of the geology will be carried on by F. L. Ransome in the season of 1900.

CHAPTER I.

OUTLINE OF THE GEOLOGY.

By WHITMAN CROSS.

LITERATURE CONCERNING THE REGION.

Hayden Geological Survey.—The country adjacent to Rico was visited by geologists of the Hayden Survey in 1874 and 1876. In the former year the late F. M. Endlich examined the district to the east, the one hundred and eighth meridian, passing through Telescope Mountain, being apparently the general western boundary of his field of work. In 1876 W. H. Holmes made a rapid reconnaissance over an enormous area of the plateau country to the west. The complicated geology of the Rico uplift, coming on the border zone between the fields of different men working in different seasons, did not receive adequate attention, and the Hayden map of this area is, therefore, quite unsatisfactory.

From his report for the year 1874 it would appear that Endlich visited Blackhawk Peak ("Station 37"), approaching it from the east, but that he did not examine any other part of the mountain group. Since no benefit can come to the present report from a critical review of Endlich's inaccurate observations and misconceptions regarding the local geology, they will be passed over with brief comment. He published two profile sections running through Blackhawk Peak, but the data of these profiles, of the published map in the Geological Atlas of Colorado, and his statements of observations do not agree, and they are all decidedly erroneous in most particulars. What Endlich saw of the Rico dome structure was interpreted as a rather sharp anticline running along Silver Creek. Some of the intrusive sheets about Blackhawk Peak were observed, but it is difficult to understand on what basis the porphyry sheet of Hermosa Peak was extended westward along the divide to the summit of Telescope Mountain. Endlich later became the superintendent of the first smelter at Rico, but he published nothing further concerning the geology of the region.

The Hayden map of the western part of the Rico Mountains is the work of W. H. Holmes, and the inconsistencies in stratigraphy about the head of the Dolores River are due to the necessary adjustment between his work and that of Endlich. Holmes established a section

of the Mesozoic formations to the west, which was expressive, adequate to the needs of the reconnaissance map, and in its general features is to-day recognized as correct. Endlich, on the other hand, had established an inadequate and partially incorrect stratigraphic section for the same formations, and where these two systems of mapping came together there was naturally a forced representation of unconformities by overlap which did not exist. This explains the drawing of the Hayden map about the Rico Mountains. The porphyry masses of Elliott Mountain and Calico Peak were observed by Holmes from a distance and represented with some approximation to correctness.

John B. Farish.—In 1892 John B. Farish read a paper before the Colorado Scientific Society entitled *On the Ore Deposits of Newman Hill, near Rico, Colorado.*¹ The description of the ore deposits was preceded by some general remarks on the geology. The structure of the mountains was recognized by Farish as a domal uplift, and concerning it he says: "The elevation of the mountains was associated in its origin with the intrusion of a laccolitic mass of porphyritic diorite, which may be seen a short distance above the town. The amount of upheaval at the center of the uplift was several thousand feet. Its longer axis is at right angles to the course of the river, and is so coincident with the corresponding axis of the laccolite." It is not evident what outcrops were assumed to represent the large laccolith, but the sheet at the northern base of Newman Hill is referred to as an offshoot from it. The rock of the laccolith is said to be probably a "hornblende-augite-porphyrity (a porphyritic diorite)," on the authority of R. C. Hills. Faults were recognized by Farish, but probably only the minor ones of Newman Hill.

The sedimentary rocks about Rico are stated by Farish to be "Lower Carboniferous and Carboniferous proper," but the grounds for the determination are not given.

T. A. Rickard. A detailed description of the Enterprise mine was published in 1896 by T. A. Rickard, then superintendent of the mine.² In this paper there are but few statements concerning the general geology. The strata about Rico are said to be fossiliferous and to belong to the Lower Carboniferous, and the common igneous rock is called porphyryite, with a concise description by R. C. Hills. Rickard refers to "a large dike of porphyryite" crossing the valley north of Rico, "making a fault which breaks the continuity of the country on either side." It would appear that this reference, as well as that of Farish, above noted, concerning the supposed laccolith, must be to the mass of schists with small dikes of hornblende porphyry; but the position and importance of the fault are not further indicated.

¹ Proc. Colorado Sci. Soc., Vol. IV, pp. 151-164.

² Trans. Am. Inst. Min. Eng., Vol. XXVI, pp. 906-980.



VIEW FROM BLACKHAWK PEAK, LOOKING NORTHEAST TOWARD THE SAN JUAN MOUNTAINS.

In the middle distance, on the right, a marked white band on the south face of an unnamed hill represents the La Plita sandstone dipping away from the point of view under the influence of the domal structure. Photograph by E. Howe.

The papers of both Farish and Rickard deal mainly with the Enterprise mine and give many important details of the geology of Newman Hill, as thus revealed, to which reference will be made further on in describing this locality.

Telluride and La Plata folios.—The first results of the resurvey of the San Juan region, now in progress, are contained in the Telluride folio, No. 57 of the Geologic Atlas of the United States, issued in 1899. The southwestern corner of the Telluride quadrangle is situated almost at the northern base of the Rico Mountains, 4 miles north of Telescope Mountain. While the structure of the Rico Mountains extends into the Telluride quadrangle but a very short distance, the Mesozoic formations there exposed are the same seen at Rico, and the discussion of several of them is fuller in the folio than in the present report. But the most important bearing of Telluride geology upon that of the Rico Mountains is in connection with the intrusive monzonite porphyries, the stocks of granular rocks, and the surface volcanic series of the San Juan. The age of the Rico dome, the conditions at Rico at the period of its elevation, and other problems of local geology must be discussed in the light of the facts observed in the Telluride quadrangle.

The La Plata Mountains, situated mainly in the quadrangle of the same name and lying directly south of Rico some 16 to 25 miles, are so analagous to the Rico Mountains in general character that their description in the folio now in press (Geologic Folio No. 60, La Plata) is in a measure supplementary to that of the Rico group. The domal structure is simpler because there are no profound faults, the intrusive porphyries are of the same general character as those of Rico, and there are several stocks of granular rocks, monzonite, diorite, and syenite, cutting the porphyry sheets.

GENERAL DESCRIPTION OF THE MOUNTAINS.

Physiographic relations of the mountain group.—The Rico Mountains form a small, compact group of peaks resulting from the deep dissection of a local dome-like uplift of sedimentary and intrusive igneous rocks. This uplift appears on the eastern border of the Dolores Plateau, which is continuous westward with the Great Sage Plain of Utah, extending to the brink of the Colorado Canyon. The termination of the Dolores Plateau on the line passing through the Rico and La Plata mountains is due to a change in the attitude of the underlying sedimentary formations. Beneath the plateau they are approximately horizontal, but on the line mentioned they come under the influence of the monoclinical folding which has taken place in a broad zone adjacent to the San Juan Mountains.

The relations of the Rico Mountains to the Dolores Plateau are well illustrated by the topographic map of the Rico quadrangle. On that sheet the plateau surface is shown crossing the western boundary with a general elevation of about 9,400 feet, rising very gradually for several miles and then merging into a gently dipping surface on the borders of the Rico uplift, a short distance beyond the limits of the special map. To the east of the Rico Mountains the country is of irregularly undulating character, modified by a few prominent peaks of intrusive igneous rocks. Pl. I exhibits the character of the zone between the Rico and San Juan Mountains as seen from near the summit of Blackhawk Peak, the highest of the Rico group. At a distance of 8 or 10 miles rise the very rugged peaks of the San Juan. In the middle ground, on the right, is Hermosa Peak, caused by an intruded porphyry mass which is probably continuous with the white cliffs of Flat Top, seen on the left hand of the view. The low mountain with a light-colored band on its southern face, about 2 miles from Blackhawk Peak, presents a beautiful section of the white La Plata sandstone, dipping gently away from the point of view under the influence of the Rico uplift.

Another view of this belt of country east of the Rico Mountains is presented in Pl. II, a photograph taken from the knoll (11,886 feet) on the divide northeast of Telescope Mountain, looking east toward Hermosa Mountain. In Pl. XIX (p. 148) is shown the character of the country between the Rico and La Plata mountains. The crest line of the central portion of the view is Indian Trail Ridge, the divide connecting the two mountain groups, which is made up of red Triassic strata dipping at a low angle southwest and passing under the Jurassic and Cretaceous beds on the right-hand border of the view.

Drainage system and vegetation.—The Rico Mountains are cut into two nearly equal parts by the Dolores River, which receives all the drainage from within the group and from its northern and southern slopes. On the western side a portion of the drainage is into the West Dolores River, and on the east heads one of the tributaries of the Animas River.

Timber line in the Rico Mountains lies between 11,500 and 12,000 feet, and its course may be traced in several of the illustrations accompanying the report. The trees and shrubs are those common in the mountains of Colorado, with perhaps greater variety than usual in the lower sheltered valleys.

Details of physiography.—A glance at the accompanying map (Pl. XXII, in pocket) shows that the Rico Mountains consist of a circle of high and rugged peaks, divided into two crescent-shaped halves by the Dolores Valley. There are twelve peaks, each exceeding 12,000 feet in elevation above sea level, and the narrow crest connecting them rarely sinks below 11,500 feet on either side of the river. In passing



VIEW LOOKING EAST FROM THE DIVIDE AT THE HEAD OF MCJUNKIN CREEK

The Needle Mountain is in the distance; on the right Hermosa Peak with a thick sheet of monzonite-porphyrty lying above the Dakota sandstone. Photograph by Cross.

through the group the Dolores receives several important tributaries on each side. These lateral gulches are all deep, with steep sides, and their streams are still actively engaged in the work of erosion.

The forms of these peaks and gulches are illustrated in the photographs reproduced on the accompanying plates. Pls. III and IV in particular show the details of form seen in the higher summits of the eastern side of the river. The photograph reproduced in Pl. III was taken from the ridge leading southeast from Expectation Mountain and exhibits the western face of Dolores Mountain rising above the gentler slopes of Newman Hill. On the right is the gorge of Deadwood Gulch, beyond which rises the porphyry summit of Whitecap Mountain. In the background appears Blackhawk Peak.

Pl. IV represents the same group of peaks as seen from Telescope Mountain, and here the true relations of Blackhawk Peak to the lesser summits are revealed. On the right hand is the double summit of Dolores Mountain, then Whitecap, and, rising above all, the mass of Blackhawk Peak and its north ridge. On the left is an analogue of Whitecap, due to a massive sheet of porphyry. In the distance on the right hand are the peaks of the La Plata group. In both of these views appear details of structure to be referred to further on.

The character of several of the western summits of the group is illustrated in the other plates accompanying this report. The Dolores Valley above Burns is shown in Pl. XVI (p. 142), and the higher portion of the town of Rico is seen in Pl. V in relation to Newman Hill.

STRUCTURE OF THE RICO MOUNTAINS.

Elements of the structure.—The Rico Mountains are due to forces which have been very local in their action. The principal structural feature is a dome-like uplift of sedimentary beds resulting from a distinct vertical upthrust. A part of the elevation of the strata is clearly due to the intrusion of numerous bodies of molten material injected between the beds, after the manner of laccoliths. The intruded magmas were indeed very similar in composition to those which by their intrusion caused the uplift from which have been carved the Henry Mountains, whence the laccolith was first described, and it is altogether probable that the intrusions of the Rico Mountains were contemporaneous with those of the Henry Mountains and of several other isolated mountain groups of the plateau country to the west, referred to as laccolithic groups. Several of these assemblages of peaks can be seen from the Rico Mountains, and the La Platas, commonly considered as of that character, are but a few miles distant.

But the elevation of the Rico dome was not in large degree due to the intruded masses of molten material, and it appears certain that a part of the upthrust occurred after the magmas had solidified into rock.

This conclusion is necessary because of the numerous and important faults occurring in the mountains, the dislocation upon which has plainly added materially to the uplift, and these faults traverse porphyry sheets as well as sediments. In the present relations of the formations it is impossible to determine very accurately how much of the uplift was caused by the igneous intrusions. It was certainly equal to the mass of the intruded magma, but as the heart of the dome has now been eaten away, the former extent of the porphyry bodies at the center of the dome can not be ascertained. A considerable disturbance must have been caused by the large cross-cutting monzonite stock on the west side of the river, but the exposures about this mass are so poor that the evidence of the part this intrusion has played is very unsatisfactory.

The structure of the Rico dome is somewhat obscured, especially on its eastern side, by an earlier structure belonging to a broad zone about the San Juan Mountains. This consisted of a dip to the south-west, which has been reversed in the Rico uplift.

Rico dome.—The general structure of this quaquaversal fold or uplift can be clearly seen from any of the higher peaks of the group; especially in the mountains on the east side of the Dolores there are many good exposures which render the structure visible at a distance, and while certain broad surfaces to the west of the river exhibit no structural details, the existing outcrops are in accord with the general conditions. The broad dome structure is expressed upon the geological map by the way in which the formation lines cross mountain slope and valley, and the symbols indicating strike and dip as determined at many points show both the prevailing structure and the local variations from it. By reference to several of the accompanying views an idea of the attitude of the strata may be gained.

In Pl. III the outcrops of the ledges of massive limestone may be traced as they rise from Deadwood Gulch across the west face of Dolores Mountain, owing to the southeasterly dip, while in Pl. IV, the same strata are seen rapidly descending to the valley of Silver Creek, under the influence of the northeasterly dip there prevailing. At various other points of both views the structure is more or less evident. The view of Sandstone Mountain, Pl. VI, exhibits the dip to the west of north present in the ridge leading to Mount Elliott.

The influence of the Rico uplift is distinctly limited in the Dolores Valley at a point about 6 miles above town, and on the southwest less definitely at nearly 6 miles distance, the north-south diameter of the visible dome being thus about 12 miles. The east-west diameter is approximately 15 miles, from a point about 3 miles east of Blackhawk Peak nearly to the West Dolores River. The vertical extent of the uplift is estimated at about 4,500 feet.



VIEW LOOKING EAST ACROSS THE DOLORES VALLEY FROM THE RIDGE NORTHEAST OF BURNETT GULCH.

On the right is Deadwood Gulch. In the center is Dolores Mountain, behind which rise the higher summits of Blackhawk Peak. On the right of Deadwood Gulch is Whitecap Mountain with its purple sheets. Across the face of Dolores Mountain may be traced the light limestone ledges of the middle Hermosa, and the general southeasterly dip prevailing in this portion of the Rico Mountains is shown by many lines of outcrop. In the foreground is the upper part of Newman Hill. Photograph by Cross.

Relation to the San Juan structure.—As shown many years ago on the Hayden map of Colorado, the entire series of Paleozoic and Mesozoic sedimentary formations exposed upon the flanks of the San Juan Mountains has been affected by a relative upward movement of the mountain area, and the strata are now seen dipping south, west, and north, away from the center of upheaval. It is clear that there have been several periods of movement, but the dominant one in producing the visible structure was that occurring at the close of the Cretaceous period. The Rico Mountains are situated directly on the line where the influence of this San Juan pre-Tertiary continental folding dies out and the strata assume the nearly horizontal attitude which they maintain under the great stretches of plateau to the west. The strata east of the Rico uplift dip southwesterly at decided angles, while those to the west pass immediately under the Dolores Plateau.

The attitude which the formations would now exhibit along the line of the Dolores Valley were it not for the Rico dome may be plainly seen from the areal maps of the Telluride and Rico quadrangles. In the southwest corner of the former, and only 6 miles northeast of Rico, the Dolores flows in a canyon whose rim rock is the Dakota sandstone lying in almost horizontal position—the floor of the Dolores Plateau over large areas. As the valley of the Dolores leaves the Telluride quadrangle the formations rise rapidly under the influence of the Rico uplift, but at the mouth of Bear Creek, 12 miles below Rico, the stream is again coursing in a typical canyon of the plateau country, the Dakota sandstone reappearing as the floor of the mesas or plateau remnants on either side. But for the Rico uplift the Dolores would be flowing in a canyon like those referred to, along the stretch where the Rico Mountains now appear. East of the valley there would be remnants of the Dakota, forming sloping mesas like those common in the Durango quadrangle.

The relative ages of the broad San Juan structure alluded to and the local Rico uplift are inferred from the facts of the Telluride quadrangle, where the Mesozoic formations are affected by the San Juan uplift and were greatly eroded before the beginning of the volcanic eruptions which characterized the early Tertiary. Yet intrusive porphyries like those of the Rico Mountains are later than the earlier volcanics, at least; so the presumption is that the Rico uplift was much later than, and entirely distinct from, the pre-Tertiary movements about the San Juan region. It may have been synchronous with some of the continental movements of Tertiary time not yet clearly differentiated from older movements in this region. This conclusion is in harmony with all the evidence available as to the age of the intrusion of diorite and monzonite-porphyry sheets like those of the Rico Mountains in other parts of Colorado.

Relation of faults to the dome structure. The map shows a large

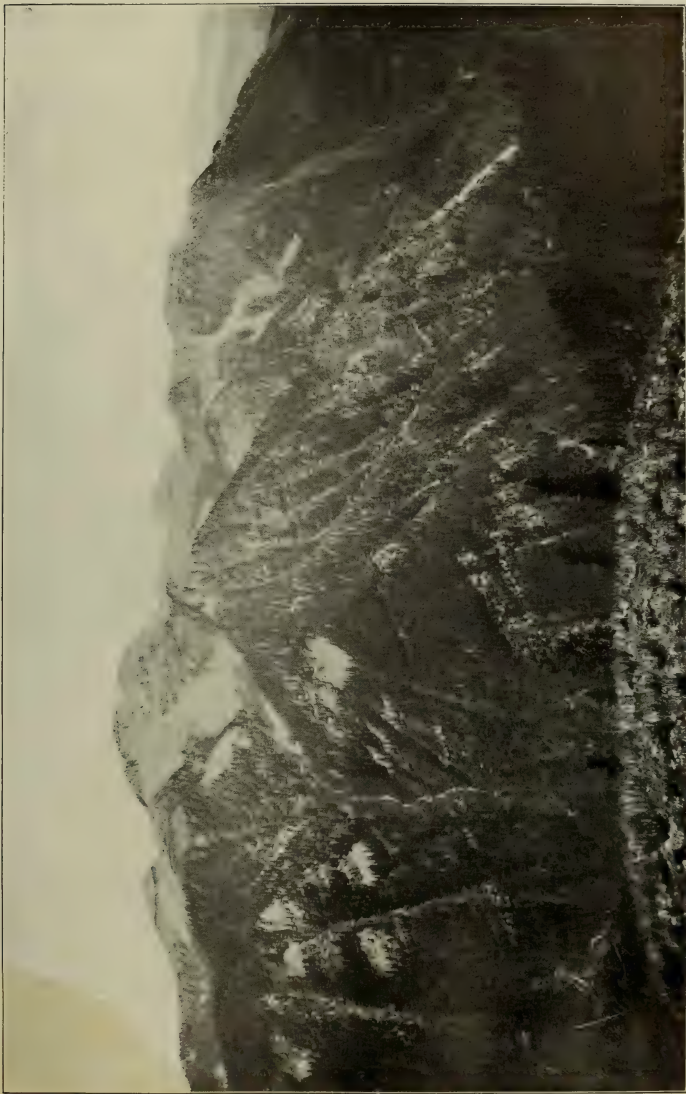
number of faults of sufficient magnitude to affect the geological mapping, and there are many others upon which the dislocation is very slight or not determinable. While there does not appear to be any definite system in the arrangement of these faults, it is true that they are for the most part confined to the area of uplift, and that their combined effect has been to increase the uplift near the center of the dome. Several of the important faults are so imperfectly exposed, owing to landside débris and other surficial materials, that the available data concerning their relations to other faults and to the domal uplift are far from satisfactory. It is reasonably certain, however, that faulting has occurred at different periods, and that the later faults are of relatively recent age.

It seems natural to assume that fissures would develop contemporaneously with domal uplift of any considerable magnitude. If the quaquaversal folding continued after the porphyry intrusions, the presence of these local and comparatively rigid masses would cause fractures in the adjustment of materials. But it appears that the fractures and dislocations just referred to must have been in large degree in the upper portions of the dome, now entirely removed by erosion, while as a matter of fact the existence of important faults beneath the Paleozoic sediments and all known porphyry bodies, and bounding blocks of Algonkian quartzite and schist, demonstrates the essentially deep-seated character of much of the observed fault fracturing.

The greater number of faults located in the outer portions of the uplift exhibit an upthrow on the inner side, if their strike is tangential or approximately so, and in such cases the faulting has added to the elevation of the central parts of the dome due to the quaquaversal fold. In other cases, however, the faults are reverse faults, or bound blocks which have sunk. In the valley of Silver Creek, where the Algonkian quartzites appear, it is often evident that the adjustment of the wedge-shaped blocks has been accomplished by many fractures, the relative importance of which it is impossible to establish. From the fault phenomena of this central region it appears that the faults represent a very strong vertical upthrust, and while some of them may have originated during the domal uplift, some of them, especially the more recent ones, resulted from a force acting more energetically and causing rupture rather than bending of the rocks.

The more detailed discussion of the faults in Chapter IV, with profile sections, gives the basis for the above general statements.

Relation of intrusive rocks to the dome structure.—The masses of porphyry, bearing more or less distinct resemblance to laccoliths in their form and relation to stratification planes, have manifestly caused an uplift of the beds above them, and as there is a distinct association of these masses with the center of uplift, their combined effect would



BLACKHAWK PEAK AND ADJACENT SUMMITS FROM TELESCOPE MOUNTAIN.

The highest points belong to the ridge north of Blackhawk Peak. Here may be seen the cliffs of a massive porphyry sheet. On either side is a porphyry-capped peak. Dolores Mountain is seen on the right, and in the distance the faint outline of the La Plata Mountains. Photograph by E. Howe

alone have produced a domal structure of some magnitude. An examination of the map shows that the larger number of porphyry masses occur at horizons above the Carboniferous in the main circle of peaks and that only one or two sheets of importance occur in the lower strata in the center of the dissected dome. The porphyry sheet of Newman Hill and the Montelores sheet are the ones in question. If the form of the porphyry occurring in Nigger Baby Hill were more plainly defined, it would possibly constitute a third body of note. But it seems hardly open to question that the main uplift of the Rico dome is disconnected from the intrusion of the visible sheets of porphyry, nor is there any evidence of concealed masses of that rock of any considerable magnitude. Until the presence of the Algonkian rocks was determined the writer entertained the working hypothesis that a large laccolith of porphyry might have been intruded at a horizon near the base of the Paleozoic formations, but the appearance of the pre-Paleozoic rocks in the heart of the mountains, with no evidence of the hypothecated laccolith, renders it improbable that the uplift can be primarily connected with porphyry intrusion. It is, then, much more likely that the intrusions are accompaniments or consequences of the local folding than that they are its cause.

The monzonite stock of Darling Ridge is large enough to have produced much disturbance of the sedimentary rocks above it—on the assumption that it did not reach to the surface—but erosion has entirely removed the rocks which could exhibit that disturbance. The lateral effect of this intrusion is almost entirely masked by landslide débris, but what little evidence there is upon this matter indicates an astonishingly small amount of disturbance in the rocks penetrated. This particular stock does not, however, differ in this respect from the larger ones of the Telluride and Silverton quadrangles or from the more nearly analogous masses occurring in the La Plata Mountains. The stock intrusion is later than the porphyry injections, and may be later than the greater part of the central uplift.

STRATIGRAPHY.

Sedimentary section represented.—In the discussion of structure it has been stated that Algonkian schists and quartzites are exposed in the heart of the Rico Mountains. These rocks correspond to the pre-Paleozoic formations which, in association with older gneisses and later intrusive granites, clearly underlie the Paleozoic series on the south side of the San Juan Mountains, revealed with especial clearness in the Animas Valley and its tributaries. The successive sedimentary formations found in the central part of the Rico dome correspond to the Paleozoic portion of the Animas section, embracing Devonian, Carboniferous, and Permo-Carboniferous formations. All of these old

geological formations have been brought to light at this point by the Rico uplift and its subsequent dissection by the Dolores River. As has been stated in an earlier paragraph, the bed of the Dolores at Rico would have been in the uppermost layers of the Triassic red beds were it not for the local uplift.

The area of the special map exhibits the full thickness of the Trias and of the lower member of the Jura, but the Cretaceous sandstone and shale normally represented in the plateau adjacent to the Dolores Canyon have been entirely eroded away from the area covered by the map, though present on the northwest and south at no great distance. Chapter II contains a detailed description of the sedimentary formations, hence the following statements are such as seem necessary to this outline.

Algonkian rocks.—The pre-Paleozoic quartzites and schists which appear as fault blocks thrust up into the Devonian and Carboniferous strata at the center of uplift are of interest as indicating the extension of these oldest sedimentaries westward under the Dolores Plateau. The locality is too near the great exposures of the Needle Mountains and of the Uncompahgre Canyon to add much to the force of the suggestion that the latter rocks may be the direct eastward extension of the great Algonkian series of the Grand Canyon of the Colorado, described by Walcott; but the evidence of the Rico outcrops, so far as it goes, is in favor of such a hypothesis.

The blocks of quartzites on the opposite sides of Silver Creek are very massive and highly indurated rocks, in which the original bedding is visible only on close examination. They resemble strata that are exposed in the Uncompahgre Canyon near the mouth of Red Creek, in the Silverton quadrangle. The schists crossing the Dolores above Rico are likewise similar to rocks known in the Needle Mountains, but as this latter complex has not yet been examined in detail, no suggestions of close correlation for the Rico exposures can be made at this time.

Devonian.—The lowest Paleozoic formations exposed in the heart of the Rico uplift have been referred to the Devonian. There are two formations thus correlated, a limestone and an underlying quartzite. The former is the highly metamorphosed rock exposed in the main street of Rico and on the banks of the Dolores. The quartzite is shown in but a few small outcrops, and the base is not revealed.

The reference of these strata to the Devonian is based more upon comparison with the Animas section of the Paleozoic than upon any direct evidence obtained at Rico. The thickness of the Carboniferous formation at Rico is sufficient, in the absence of contrary evidence, to warrant the opinion that the limestone in question belongs to the Devonian, and the thickness of the limestone and the character of the fossiliferous Carboniferous strata just above it and of the quartzite



DOLORES MOUNTAIN AND NEWMAN HILL FROM THE WEST SIDE OF THE RIVER, NEAR IRON CREEK.

Shows the houses in the upper part of Rico, the relation of Newman Hill to the valley and to Dolores Mountain, the central summit of the view. The general structure is apparent from the ledge outcrops crossing the slopes above Newman Hill. Photograph by E. Howe.

below, indicate that the correlation is correct. The limestone exposed at several points on the Atlantic Cable claim exhibits an unusual structure, due undoubtedly to metamorphism. It consists of white granular marble in pure masses, an inch to a foot or more across, separated by a dark-green network of dense texture, composed chiefly of iron-bearing silicates. The exposures of this rock do not satisfactorily indicate its thickness, but a bore hole was sunk in it by the Atlantic Cable Company, which was prompted to its exploration by the nests of galena, magnetite, and other ores outcropping locally on the surface. The bore hole showed the limestone to have a thickness of 150 feet, and to be underlain by quartzite, in which the drill was stopped after penetrating to a depth of 343 feet. As explained by Mr. Spencer (Chapter II), it must be inferred that the bottom of the drill hole is very near the base of the quartzite, assuming the limestone to be Devonian.

The metamorphosed limestone, if Devonian, is equivalent to what has been called the Ouray limestone, because of its typical development near the town of that name.¹

Carboniferous.—A glance at the geological map shows that the greater part of the interior of the Rico Mountain group is composed of the Hermosa formation, of which three divisions may be made for purposes of description. The lower division consists chiefly of greenish-gray sandstones and shales, the latter being sometimes nearly black. The middle member is characterized by many bands of massive dark-gray limestone, often highly fossiliferous, alternating with sandstones and conglomerates. The upper division is predominantly a complex of shales, with occasional limestones.

The massive limestones of the middle member of the group form the most prominent outcrops of the entire formation. They are most marked on the west face of Dolores Mountain, on the banks of Silver Creek, and in Sandstone Mountain, as illustrated in Plates III–VI. The lower member is more friable in texture and forms less prominent exposures. The upper division corresponds more nearly to the succeeding formations in lithological character, and forms many ledges and cliffs at the horizons of its more massive conglomerates and sandstones.

Most of the limestone layers throughout the formation are to some extent fossiliferous, and from the extensive collections which have been made it appears that the 1,800 feet of strata belong to one paleontological unit. The complex of strata characterized by this fauna is here named the Hermosa formation, from its typical development in the region of Hermosa Creek, a prominent western tributary of the Animas River, heading a few miles directly east of the Rico Mountains.

Permo-Carboniferous.—Succeeding the Hermosa formation comes

¹ Arthur C. Spencer, *Am. Jour. Sci.* 4th series, Vol. IX, 1900, pp. 125–133.

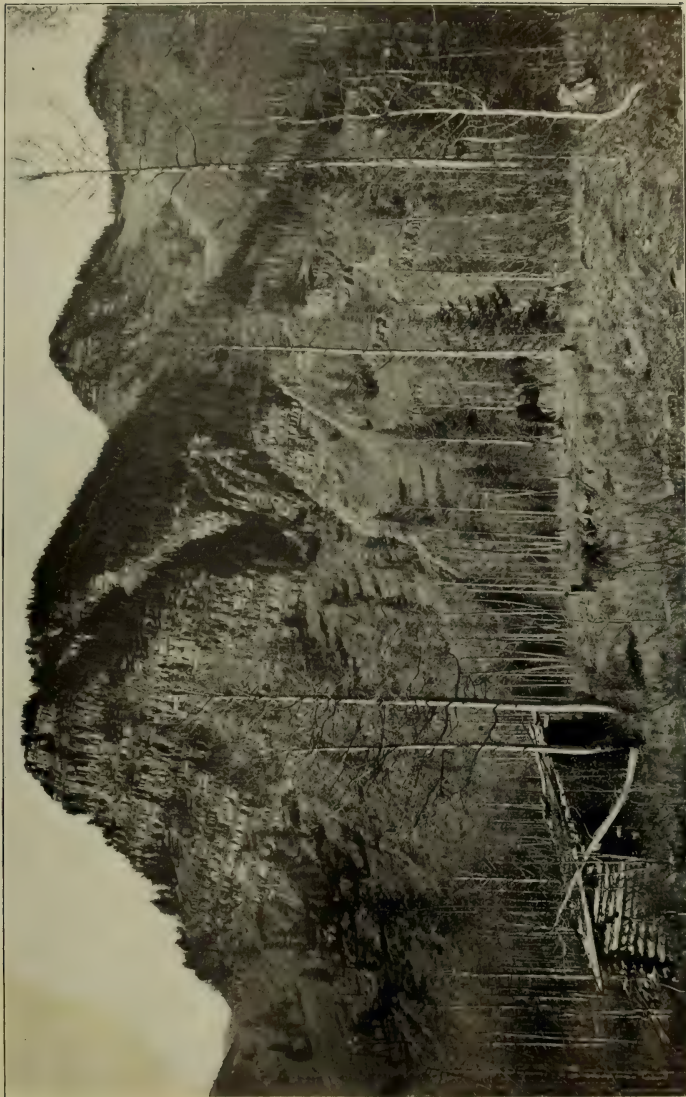
the great "Red beds" series of southwestern Colorado, in the upper portion of which Triassic fossils have been found at many localities.¹ The change from the prevalent grayish tones of the Carboniferous strata to the distinct dull-red hues of the next higher beds is in general a rather sharply defined one, and the lower limit of the Triassic would undoubtedly have been drawn upon that criterion had the closer study of the section not revealed an important invertebrate fauna of Carboniferous affinities in several calcareous strata of the lower 200 or 300 feet of the reddish complex. This discovery, first made by Mr. Spencer, has led to the recognition of a persistent and well-defined formation which, on the authority of G. H. Girty, is referred to the Permo-Carboniferous, as expressing the fact that its fauna is intermediate in character between that of the true Permian of the Missouri Valley and the Carboniferous.

Juratrias.—The sedimentary section between the Rico and the Dakota formations is subdivided in the Rico region, as in the Telluride quadrangle, into three formations. The lowest of these is named the Dolores formation. It embraces here about 1,800 feet of strata, for the most part of the usual character of the Red beds, as known in Colorado. Fragmentary remains of dinosaurs and crocodiles of Triassic types occur in the upper part of the formation throughout the San Juan region and adjacent parts of the plateau country to the west. The fossiliferous portion of the formation is characterized by peculiar fine-grained limestone conglomerates and gray fissile sandstones and shales, but is by no means free from red sandstones and grits similar to those which prevail in the lower part. Detailed sections showing the constitution of the Dolores formation are given in the next chapter, together with a discussion of its relations to the Rico beds.

Succeeding the Dolores formation comes the La Plata sandstone, of assumed Jurassic age. This formation consists essentially of two massive, white, quartzose sandstones with a variable and subordinate, darker, calcareous series of shales, etc., between them. The thickness of the La Plata varies in the Rico region from 250 to 500 feet. It is present not only in the western part of the area of the special map, but is found on the borders of the dome on the north, east, and south as well.

The third member of the Juratrias, and the uppermost of the Mesozoic formations preserved in the area of the accompanying map, is the McElmo formation. This consists of alternating fine-grained sandstones and variegated marls or clays in a total thickness of 500 feet, of which only the lower portion is preserved in the area mapped. The McElmo strata are lithologically very similar to the Morrison beds of

¹Geologic Atlas U. S., folio 57, Telluride, Colo.



SANDSTONE MOUNTAIN FROM THE FOOT OF C. H. C. HILL.

The view shows the almost vertical cliffs of Sandstone Mountain, consisting of alternating limestone, sandstone, and shale. The crevice crossing the summit is occupied by a small fault. Photograph by Cross.

the foothills of the Front Range, so celebrated for their dinosaurian fauna of Jurassic types, and occupy a corresponding position with regard to the Dakota formation.

IGNEOUS INTRUSIONS.

The geological map represents a large number of masses of igneous rock, of varying size and form, distributed throughout the Rico Mountains from the center to the outskirts. Similar rocks occur, in fact, at scattered points over a large area about the mountains, but it is plain that the center of uplift was also a notable center of eruptive activity. Viewed from the standpoint of their geological occurrence, the igneous masses may be classified as intrusive sheets, stocks, and dikes. The former acted collectively to add to the domal uplift caused by folding and faulting. The stocks have cut directly across the strata at the horizons now exposed and do not visibly affect the general structure. The dikes are the filling of narrow fissures and were formed at several periods.

Intrusive sheets.—Intrusive porphyry bodies, which may be called sheets, occur throughout the sedimentary section from the base of the Hermosa (Carboniferous) to the Cretaceous. Their distribution, both geographic and stratigraphic, and the forms of the outcrops are shown on the geological map. The original form and extent of many of these porphyry bodies are not now determinable, since they occur in the higher peaks, and the remnants left by erosion may represent either extensive or local masses. There are, however, numerous bodies possessing a lateral extent many times their thickness intruded at or near a definite horizon, and these must be called sheets or sills. Of other masses, such as those forming the summits of Elliott and Whitecap mountains, there is little evidence of the original shape except that their bases are conformable to the strata below. No definite dome-shaped porphyry mass or laccolith has been observed in the Rico Mountains, and such thick sheets as those present in Blackhawk Peak and elsewhere are large enough to have produced isolated remnants like those of the summits above named.

The statement by Farish in the article already cited, that a laccolith, supposed to have played the principal rôle in the Rico uplift, is visible just above the town, may have had reference to the monzonite stock of Darling Ridge or to the Algonkian schists shown on the map. The hypothesis that the elevation of the strata was due to a buried laccolith was a natural one in view of the presence of so many porphyries nearly identical with those of the Henry Mountains in composition and structure, but no evidence of such a mass has been found.

While some sheets follow definite horizons for the entire extent of present exposures, others cut across from one stratification plane to

another or split into two or more branches. These evidences of the intrusive character of the porphyries are abundant. By extended cross-cutting courses at angles oblique to the stratification transitions between sheets and dikes are formed, and these bodies are by no means rare. It seems probable that whole groups of porphyry masses, such as those in and about Blackhawk Peak and those in the summits around Anchor Mountain, were contemporaneous in origin and connected by many cross-cutting arms. In the latter region especially much evidence of this connection is visible and has been expressed on the map.

The largest sheet now preserved, and the one occurring at the lowest horizon, is that at the northwest base of Newman Hill. It has a thickness of at least 500 feet, and its lateral extent may be much greater than the portion seen.

The rocks of the intrusive sheets are of a type common in the mountains of Colorado and in the isolated groups of the plateau country. They are all pronounced porphyries, with many small white plagioclase crystals, with smaller prisms of hornblende, and occasionally crystals of quartz, all embedded in a gray fine-grained groundmass, which consists chiefly of orthoclase and quartz. Some variation in the proportions of the constituents occurs without any marked change in habit, except that either a decided increase in the amount of hornblende or its development in very minute particles causes a darker color. All the sheet rocks and many dikes are included petrographically under a single name, monzonite-porphyry, expressing the composition, in which the alkali feldspar, orthoclase, and the soda-lime feldspar, plagioclase, are estimated to play approximately equal rôles. The further composition of the rock is expressed by saying that it is a quartz-bearing hornblendic monzonite-porphyry.

Cross-cutting stocks.—The large mass of quartz-monzonite on Darling Ridge is a type of the eruptive body known as a stock. This body exhibits no tendency to spread out laterally on stratification planes, but cuts almost vertically across every rock in its path. It has no regular outline and its original upper limit is entirely a matter of inference. No doubt it penetrated to much higher levels than those now seen, but there is no instance known to the writer where the upper extremity of such a stock is exposed, although in the San Juan Mountains similar rocks are found cutting the highest bedded volcanics now remaining.

The stock contacts are mainly concealed by landslide or other débris; hence there is more or less assumption in the statement that the sheets of porphyry coming in contact with the stock are invariably cut by it. Yet the complete correspondence between the eruptive phenomena of the Rico and La Plata mountains makes it probable, in the absence of any contrary evidence, that the two forms of occurrence bear the same

relations in the two localities. In every locality thus far known to the writer where these forms of occurrence are associated the stocks cut the sheets.

The rock of the Darling Ridge stock is a typical monzonite, similar to that of certain stocks in the La Platas and to that in the great stock of Grizzly Peak, in the southwest angle of the San Juan Mountains, or in Sultan Mountain, near Silverton. It appears like a diorite at first sight, and would have been so called a few years ago, but a pink alkali feldspar, orthoclase, is associated with an equal or larger amount of white soda-lime feldspar, throwing the rock into the new group proposed by Brögger, intermediate between syenite and diorite. There are many rocks of this character in Colorado and elsewhere in the Rocky Mountains, and the new division is a very welcome one to petrographers working in these districts. As will be shown in Chapter III, the presence of a small amount of quartz brings the Rico monzonite into close relation with the quartz-diorites and the quartz-bearing syenites.

Later dike rocks.—While the hornblendic monzonite-porphyry intrusions and the monzonite stock are by far the most important of the igneous masses in the Rico Mountains, two other eruptions have been recognized which have considerable interest from the theoretical standpoint. These two eruptions produced rocks of very different character, the one containing numerous large orthoclase crystals and being a strongly marked porphyry, while the other type is a very dark, dense, aphanitic rock, few of the mineral particles being determinable by the unaided eye.

The rock characterized by large orthoclase crystals occurs in several dikes in a band running east and west through Johnny Bull Mountain. Its most prominent dike, and also the longest shown on the map, crosses the divide between Calico Peak and Johnny Bull Mountain. The rock is in composition a monzonite-porphyry in which orthoclase assumes a prominent position in large phenocrysts, while plagioclase occurs in part in the groundmass. The rock is more closely related to the stock monzonite in composition than to the earlier hornblendic monzonite-porphyry. Its dikes cut many sheets of the latter rock, establishing the time relation of the two varieties, but, so far as observed, it does not come in contact with the stock monzonite, and it is therefore not definitely known which of these rocks is the older.

The dark aphanitic rocks occur in narrow dikes scattered sparingly all through the mountains and probably for many miles about them. Similar dikes have been noted in the vicinity of most of the diorite and monzonite stocks of southwestern Colorado, and they are always later than any other intrusive rock of the regions where they have been found wherever relative ages could be determined. In the Rico Mountains but one dike was seen cutting the stock rock. The small

size of the dikes make them quite inconspicuous and they can seldom be traced for considerable distances.

In Chapter III will be given the reasons for naming the aphanitic dike rocks of the Rico Mountains olivine-bearing *augite-vogesites*. Perhaps they do not all belong to this type, but the questionable ones are much decomposed and their original constitution is a matter of conjecture.

The theoretical interest of these vogesites is that they may be regarded as products of magmatic differentiation from the monzonite magma, which is clearly the principal one of this eruptive center.

CONTACT METAMORPHISM.

Contact metamorphism of the calcareous strata adjacent to the monzonite stock is very pronounced at nearly all places where the former rocks are exposed in the vicinity of the intrusive. The character of the metamorphism is such as might be expected from the action of such mineralizing agents as chlorine, fluorine, and heated water carrying those gases and perhaps others in solution. The metamorphism referred to consists in the formation of garnet, pyroxene, vesuvianite (?), and possibly other silicates of alumina, with magnesia, iron, and lime, and in the deposition of specular iron in scales, either impregnating the rocks or, more commonly, in thin crusts in fissures. Such alteration of the calcareous strata may be seen on the north side of Darling Ridge, near the Blowout in Horse Gulch, and down near Piedmont. If the metamorphosed stratum is a limestone the matrix for the silicates named is usually white crystalline marble.

The great metamorphism of the Devonian limestone in the Dolores Valley at Rico is so clearly of the character known as a contact phase of the kind described that it is considered probable that this change is also due to the monzonite intrusion. The eastern end of the monzonite is just above the street in Piedmont, and there must have been fissures traversing the strata in the prolongation of the principal axis of the stock. These may have given heated solutions the necessary access to the limestone at the places now seen. So far as observed, such contact metamorphism is confined to the zone about the stock with the exception of one place in the shattered zone, between the forks of the Blackhawk fault, where garnet masses and specular iron occur near a small porphyry dike.

VOLCANIC PHENOMENA.

Solfataric action.—While no evidence can ever be discovered proving that the surface phenomena ordinarily known as volcanic attended the deep-seated intrusions in the Rico dome, there have been certain processes active in the horizons now revealed by erosion which are generally supposed to characterize zones near the surface. One of



CALICO PEAK FROM THE SOUTH.

Shows the cliffs of alunite rock and the talus slopes which conceal its contacts. Photograph by Cross

these processes is the decomposition of rocks by sulphurous vapors, or by solutions that have absorbed those vapors, and the production of the hydrous sulphate of alumina and potash called alunite. This substance is formed at the surface in the crater of Solfatara, near Naples, and is a common product of the sulphurous emanations of volcanoes known from this locality as solfataric exhalations. But the process is not necessarily connected with solfataras of typical volcanoes, and the term has been gradually extended to cover the metamorphosing action often consequent upon eruptions which have been accompanied by mineralizing agents of sulphurous character, even when taking place in depth.

The orthoclase-bearing porphyry mass of Calico Peak has been almost wholly decomposed by such agents, alunite and kaolin being the principal products. The rock now appears as a white porphyritic mass of quartz and kaolin, but closer examination reveals much alunite. These rocks of Calico Peak are more fully described in Chapter III, with chemical analyses.

Existing sulphur springs.—It is especially noteworthy in connection with the evidence above given of former intense solfataric action, that there are numerous springs of water heavily charged with sulphureted hydrogen issuing to-day from the slopes of Stoner and Bull creeks and of other tributaries of the West Dolores north of Bull Creek. As noted by Mr. Spencer in Chapter VI, the waters of these springs are surface waters, as they are influenced directly by rainfall and dry up at times, but the sulphurous gases escape continuously. The presence of these springs on the west side of the dome only, in an area extending from the immediate vicinity of the solfataric center at Calico Peak toward the West Dolores, suggests that these exhalations really belong to a later solfataric period of this eruptive center.

Carbonic acid exhalations.—The water of several springs issuing from the gravels of the Dolores stream bed near the Shamrock tunnel, in the town of Rico, are very highly charged with carbonic acid gas. Other springs of similar character occur at several places in the valley above the town, and the calcareous spring waters also carry some excess of this gas.

In several tunnels driven into the west bank of the Dolores near Rico, in a bore hole on the Atlantic Cable claim, in the Rico-Aspen property, and at many other points in the district, carbonic acid gas has been encountered, often under considerable pressure, reaching as much as 55 pounds to the square inch in the case of the Atlantic Cable drill hole.

ORE DEPOSITION.

After the uplift of the Rico dome, the intrusion of the igneous rocks, and at least a portion of the fault fissuring, there was a period of extensive ore deposition in the rocks now forming the Rico Moun-

tains. While the age of the ore deposits can not be closely determined, it is in every way probable that they correspond in time to the deposits of the La Plata Mountains and that they belong to the great epoch of ore deposition which succeeded the early Tertiary igneous intrusions or more typical volcanic eruptions in many parts of the Rocky Mountains. Apparently the more typical laccolithic mountain groups of the plateau country to the west do not contain ore deposits in an abundance at all corresponding to their development in the La Plata and Rico mountains, but whether that fact is connected with their situation, remote from the great centers of eruptive activity, or to local causes can not now be determined. It would, however, appear natural that more extensive deposition of ore minerals should occur in a center like the Rico Mountains, where there has been so unusual an amount of fissuring, affording channels for the circulation of metal-bearing solutions.

In view of the forthcoming special report upon the ore deposits of the Rico region, by Mr. Ransome, the treatment of these masses in this place must necessarily be restricted to their general geological features. The ores occur in veins, in shattered zones of both sedimentary and igneous rocks, as replacements of limestone and of other rocks in less degree, and as variable impregnations of country rock. In mineralogical character the ores are principally sulphides of iron, lead, copper, and zinc, which are variably argentiferous and rarely have a small value in gold. Rich silver minerals occur sprinkled through the ores of Newman Hill and of some other localities. Many of the known large bodies of pyrite are too low in precious-metal values to be of present economic importance. Descriptions of the mines of Newman Hill by Farish and Rickard have been referred to in an earlier section of this chapter.

EROSION OF THE RICO DOME.

As explained in detail in Chapter IV, it is evident that the dissection of the Rico dome and the production of the existing topography must have taken place before the epoch of local glaciation and before the beginning of the landslide epoch. It therefore occurred in a time interval for which we have no chronological criteria to apply in this case. The evidence of the age of the igneous intrusions has been given, and all that can be said with certainty is that the dissection must have occurred after the uplift, and that it was practically complete before the landslides began and before the local glacial epoch.

How the Dolores River came to cut its way through the heart of the Rico dome rather than through the much softer sedimentary beds to the west is a problem of much interest. But upon this question there is little evidence now remaining, for the erosion of the whole country

adjacent to the San Juan has been so extensive that all conceptions of the surface conditions determining the Tertiary drainage systems of the region are extremely hypothetical.

RECENT GEOLOGIC HISTORY.

Since the great erosion by which the Rico Mountains were produced the history of this district can be quite clearly read in the arrangement and character of the superficial materials now seen in the valleys and on the mountain slopes. Where sculpturing of the mountains has taken place in the higher portions of the district there is evidence—which will be apparent later on—that the streams have cut but little into the solid rock in all the lower parts of their courses. In the higher parts of the mountains, however, the ordinary atmospheric agencies have been active and large amounts of talus and slide rock are seen on many of the steeper slopes.

The greatest change in the physiography of the region since the great erosion has been effected through the agency of landslides. Throughout the larger tracts which are shown on the map the landslides have modified the form of the ridges and mountain slopes and have to some degree filled up the valley bottoms, especially of the Dolores opposite C. H. C. Hill and of Horse Creek. Apparently the streams in their lower courses have not as yet been able entirely to remove this landslide débris.

Glaciation of the Rico Mountains has been confined to the upper levels and to the narrow stream beds. At least, the evidence of glaciation to be determined from débris and forms of erosion does not indicate that any very large part of the mountains was covered with glacial ice.

In the valley of the Dolores there are various deposits of stream gravels, and the map shows the distribution of the more recent deposits. Remnants of terraces in several places indicate former deposits, but these are not always clearly distinguishable from débris of other origin.

While the lateral tributaries of the Dolores have no bottom deposits of importance, several of them have built up very decided alluvial cones at their mouths. The more important of these are represented on the map.

Small deposits of calcareous sinter or tufa have been noted at various points on the banks of the Dolores, and several of them are shown on the map. At a number of these points the spring waters are still highly charged with carbonate of lime, and deposition is still going on.

The map exhibits several areas in which the surface materials so obscure the underlying hard rock geology that it has not been deemed wise to represent the underlying formations in these areas. The

nature of the surface materials in these places is generally a complex consisting largely of rearranged landslide *débris* mingled with ordinary talus and wash, and not infrequently a growth of timber or of grass conceals the nature of the rock *débris*.

It will be noted that the effect of nearly all of these recent agencies is to modify the form of the mountains existing before the glacial epoch and the beginning of the landslides by producing gentler forms of the ridges and by filling up in some degree the various valleys.

CHAPTER II.

THE SEDIMENTARY FORMATIONS.

By ARTHUR COE SPENCER.

ALGONKIAN.

Introductory statement.—The rocks which are here described as Algonkian occupy a small area in the center of the Rico Mountains, where they have been exposed by the deep erosion of the overlying Paleozoic strata. They comprise quartzites and quartzitic schists and are similar in every way to the series of rocks exposed in the upper part of the Animas Canyon and in the adjacent portions of the Quartzite or Needle Mountains, in which region they were represented on the Hayden map as “metamorphic Paleozoic,” since it was the belief of the geologist who discovered them that these semicrystalline and indurated rocks had been derived from Paleozoic strata by the processes of metamorphism. That this view is entirely incorrect is now clearly established by the known relations which the unmetamorphosed Paleozoic strata bear to the much older and much altered series upon which they lie in unconformable sequence. The basal member of the Paleozoic in the Needle Mountains is a quartzite which contains pebbles and bowlders of schist derived from the rocks upon which it rests, thus indicating conclusively that the metamorphic series existed in its present condition before the first Paleozoic beds were deposited.

The sedimentary origin of the metamorphic rocks of the upper Animas Canyon was recognized by Endlich and has since been reaffirmed by Emmons¹ and Van Hise², who have assigned them to the Algonkian, into which great geological group they naturally fall, since the Algonkian is by definition made to include all recognizable pre-Cambrian rocks of sedimentary origin.

Detailed description of the San Juan Algonkian is beyond the scope of the present paper, but since the phenomena presented at Rico are of themselves inadequate for drawing conclusions so far reaching as

¹ Orographic movements in the Rocky Mountains: Bull. Geol. Soc. Am., Vol. I, 1890, p. 257.

² Pre-Cambrian rocks of North America: Bull. U. S. Geol. Survey No. 86, pp. 320, 325.

some it is desired to present, a few general considerations concerning the Algonkian may be here given without stating data from which they are deduced. Those who are not familiar with the wider generalizations of geology will thus be enabled better to understand the significance which attaches to the extreme differences of rock character observed in the Paleozoic and pre-Paleozoic formations.

The Algonkian rocks were originally formed as sediments at the bottom of the sea, just as the later stratified rocks were formed, and, like them, were made up of shales and sandstones, probably with bands of impure limestone. From the time when their deposition was completed a very long period elapsed before the formation of any other strata of which we have knowledge, and during this period there ensued one of the greatest geological revolutions known, so widespread that it is recognized over a large part of the world. In the course of this disturbance the strata, which had been piled up to a very great but unknown thickness, were subjected to processes of physical and chemical change by which they were folded and dislocated and metamorphosed until their origin as sediments is now frequently very much obscured. Some time during this period these formations were intruded by igneous rocks of different kinds, which have in many cases also suffered metamorphism. After folding, the originally horizontal strata were left in various attitudes, for the most part greatly inclined. Subsequently the upturned edges were planed down to great depth by erosional processes ensuing upon continental uplift.

Relations of the Rico Algonkian.—The correlation of the pre-Paleozoic rocks of Rico with the Algonkian is based upon evidence of a structural nature and upon lithological resemblance to rocks of the Animas Canyon.

In the northern part of the Animas region of pre-Paleozoic rocks there is a general east-west trend, which is well brought out by a broad band of quartzite that forms one of the most prominent elements of the series. Standing at a high angle of inclination, this quartzite may be traced from the headwaters of the Rio Grande north of the Needle Mountains westward across the Animas to the northern peaks of the West Needles, and thence to where they are covered by the flat-lying Paleozoic rocks on the west side of Lime Creek. The distance through which this structure is thus known to persist is more than 12 miles, and if continued for an equal distance in the same general direction would carry the quartzites to Rico. It is, therefore, a fair inference that the Algonkian quartzite at Rico represents some part at least of the Animas series, and that it probably corresponds directly with the prominent quartzite mentioned.

The quartzites in both places are vitreous and for the most part medium or fine grained, though conglomerates are not wanting,

Along the Silverton wagon road near Lime Creek the conglomerates are very coarse, but nothing above medium coarseness is exhibited at Rico. In both regions cross bedding is well marked, and the color varies from white to red. Associated with the quartzite in the Animas region and at Rico there are other rocks of undoubted sedimentary origin, such as quartzitic schists, and in the former localities dark indurated shales of more or less schistose structure. Also in both regions there are igneous rocks in the form of dikes usually parallel with the bedding or structure of the schists. In many or perhaps most cases these igneous rocks have been metamorphosed with the rocks in which they are intruded.

Description of the quartzites.—The Algonkian rocks, very imperfectly exposed at Rico, consist of quartzites and quartzitic schists bearing small amounts of mica. The former are not distinguishable in character from other massive quartzites, to be described later, which are supposed to be of Devonian age; but their exposed thickness is greater, being more than 350 feet, probably at least 500 feet, while that of the younger formation is probably not more than 200 feet. The quartzites, as a rule, stand at steep angles. They are white or tinged with brown, with occasional red or rusty bands. The detrital material of which they are composed is almost entirely quartz, usually in small even-grained particles, but sometimes occurring in the form of pebbles less than an inch in diameter. The rock is completely indurated by the interstitial deposition of quartz, so that it is now glassy quartzite of the hardest kind, very resistant to erosion and to the miner's drill. Distinct partings between the beds of quartzite are nowhere observable in present exposures. However, the bedding or stratification planes may frequently be made out from a study of the massive quartzites where differences of grain are found or where cross bedding is observable. Ripple-marked surfaces are also occasionally seen. These structures, when taken with its constitution, are conclusive evidence of the sedimentary origin of the quartzite.

Description of the schists.—The remaining Algonkian rocks may be termed schists, since they have a more or less distinct foliated structure not due to original bedding but superinduced by metamorphism under stress. In these schists the stratification may be made out in some cases by differences in the character of adjacent bands, and to this feature the foliation is generally, though not always, parallel. The direction of foliation does not vary greatly from east and west, and its position is nearly vertical wherever observed.

The schists are dense bluish-gray rocks, the foliation being caused by the arrangement of very minute particles of biotite and actinolite, not recognizable to the unaided eye. A delicate luster is visible on the planes of easier fracture, but the schistosity is never very highly developed and the rocks often break readily across the structure with almost conchoidal fracture.

Under the microscope the main mass of most of these rocks is found to be a fine-granular aggregate of feldspar and quartz. A little of the feldspar is visibly twinned according to the albitic law. The amount of orthoclase is difficult to determine on account of the small size of the grains. Biotite is always abundant in minute light-brown flakes, in excess of the more variable pale-green actinolite needles. Epidote is more or less irregularly abundant throughout the rocks, and is especially developed in veins or adjoining fissures traversing the rock. Small amounts of magnetite dust and apatite needles are present.

In a few places the rock has quite clearly the character of a shearing product of an apparent porphyry in which there were phenocrysts of quartz and feldspar. There is a slight development of tourmaline in such rocks. The further description of these schists must be deferred until the large areas of similar rocks in the Needle Mountains have been investigated.

Intruded into these schists, in general parallel to the structure, but sometimes crosscutting, are many thin dikes of a dark porphyritic rock. These are prominent on both sides of the river, but have not been found in the Algonkian quartzites nor in any other rock than the schists; hence they are supposed to be very old intrusions, independent of the other eruptions of the region. This idea is substantiated by the shearing of some of the dikes. Stout prisms of hornblende are the only prominent crystals of the rock. There is also much secondary hornblende and epidote revealed by the microscope. The former subordinate feldspathic constituent is so much crushed and altered that the original character can not be determined. Plagioclase was probably predominant over orthoclase.

Occurrences.—The Algonkian rocks of the Rico Mountains all occur within an area of less than 90 acres, roughly estimated, but within this limited area the structure is so complicated and the rocks are so much covered that the relations of adjacent exposures can rarely be made out. On this account the relation which the schists and quartzites bear to each other has not been ascertained, for they occur in different fault blocks, and it is possible that the Devonian and Algonkian quartzites have been confused in some cases.

There are six separate areas of quartzite, and one of these, that south of Silver Creek, below Allyn Gulch, is certainly Algonkian, on account of its great mass; another, on the opposite side of Silver Creek is probably of that age, while the others have been provisionally assigned to the Devonian. In the first place mentioned the quartzites have their greatest development. They are bounded on the east by a well-marked fault, shown in the Lacey mine; thence toward the southwest they may be traced for a quarter of a mile along the hillside, upon the slope of which their outcrops are to be seen between

the elevations of 9,200 and 9,500 feet, showing a continuous exposure at one place to a thickness of 350 feet, though from the structure it is probable that a greater thickness is present. The strike and dip may be determined in this region, and while both are variable, the former is generally about N. 10° – 30° E., and the latter is steeply toward the south of east.

On the north, south, and west the boundaries of this mass of quartzite are not known, since they are covered by surface *débris*; but from the adjacent occurrences of porphyry belonging to the thick sill of Newman Hill it is almost certain that the quartzite is limited upon the south and west by faults, in the manner indicated on the map, while on the north it may connect underneath the valley wash with the quartzite upon the north side of Silver Creek. Within this latter area the rocks are very imperfectly exposed, except in local patches, but from these and from the data derived from tunnels and prospects it is definitely known that the northern limit is along the Last Chance fault, which has a nearly east-west course. The highest exposures are near this fault, at about 9,400 feet, and the quartzite can not extend much beyond this point, since green shales and sandstones are exposed at about the same elevation in the draw below the Alma Mater mine.

DEVONIAN.

General relations.—The strata which are here described as Devonian are believed to correspond definitely with a similar series which has been carefully studied in the Animas region, where the relations to the pre-Paleozoic and to the Carboniferous are well exhibited, and where a well-marked Upper Devonian fauna occurs. This series of the Animas Valley has recently been discussed in a paper entitled *Devonian Strata in Colorado*.¹ In this paper the name "Ouray limestone" was applied to the calcareous and fossiliferous member of the series, the uppermost of three divisions which constitute the complete normal section below the Carboniferous. The middle member is a shale and the lower a massive sandstone or quartzite, frequently conglomeratic in the lower part. In certain localities in the San Juan the quartzite was not deposited upon the Algonkian, and elsewhere both the quartzite and the shale are missing, in which case the limestone rests directly upon the pre-Paleozoic; but whenever the lowest member is present it is always followed in order by the other two in conformable sequence. It is possible that the shale and quartzite are pre-Devonian.

When the massive marbleized limestones at Rico were noted at the base of the Carboniferous section it was at once suggested that they probably represented the Ouray limestone, and when later evidence

¹ Arthur C. Spencer, *Am. Jour. Sci.*, Vol. IX, 1900, pp. 125-133.

of quartzites lying unconformably upon the upturned edges of the Algonkian schists was discovered, even though the supposed intervening shales were nowhere exposed, the identification was considered satisfactory; and finally, when a fossiliferous stratum belonging to the Carboniferous and characteristic of the lowest part of the Hermosa formation was found only a feet above the massive limestone the correctness of the correlation was placed beyond question.

For the Rico region it has been found necessary to group together all the members of this series and to represent them on the map by a single color, but since the series is represented in adjacent fields by two formations it is not desirable to give it a formation name, and it will therefore be designated by the name of the great time era to which it belongs. This usage is, however, entirely a matter of convenience and must not be construed as indicating that the lower part of the series is surely Devonian, since there is still some room for doubt whether the quartzite may not belong to the Silurian.

The aggregate thickness of the Paleozoic beds below the Carboniferous in the San Juan region is about 400 feet as a maximum, and at Rico this figure is closely approximated, so far as imperfect exposures allow of estimation and as indicated by the record of the boring made upon the Atlantic Cable claim in the town of Rico. This record, which was published in a paper upon the Enterprise mine by T. A. Rickard,¹ is here given:

Section of Atlantic Cable claim.

	Feet.
Limestone	7
Lead and zinc ore	4
Limestone	5½
Lead and zinc ore	5
Limestone	13
White marble	20
Zinc blende ore	3
Specular iron ore	18
Limestone	43
Porphyrite	1
Limestone	25
Porphyrite	2
Limestone	3
Mineralized porphyrite	3
Porphyrite	21
Quartzite	170
Total	343

The rocks penetrated evidently represent a thickness of strata somewhat less than the whole of the Devonian, since the top of the boring is below the top of the formation, and the bottom of the quartzite was not reached. From surface exposures the thickness of

¹Trans. Am. Inst. Min. Eng., Vol. XXVI, 1896, p. 917.

the quartzite is believed to be about 200 feet, and perhaps 20 feet should be added to the limestone series, so that the whole apparent thickness of the Devonian would be 393 feet, but from this 33 feet must be subtracted for intercalated igneous rock, and possibly half as much because of the inclined position of the strata, so that 350 feet may be taken as approximately the thickness of the Devonian.

The quartzite.—The basal member of the Devonian is a massive quartzite, very dense and highly indurated. Its colors are dull yellow to white, with red and brown staining. The material of which it is composed is mostly quartz, and only slight variation in grain is observed, the mass of sandstone being fairly homogeneous. The stratification is sometimes discernible, though usually obscured by jointing and rifting.

The Devonian quartzite is not distinguishable lithologically from that of the Algonkian except by its more regular bedding, but its lesser thickness and the unconformable attitude which it bears to the Algonkian schists, together with its relation to the shales which overlie it in places, serve to separate it from the older formation in certain cases, though in others there may be doubt as to the correctness of assigning given exposures to one or the other of the quartzite formations. The best notion of the relation of the quartzite to the overlying limestone may be obtained by following along the west bank of the Dolores River from the Shamrock tunnel to the quartzite exposure above the Piedmont wagon bridge. Here the strata are all dipping southward, and though a portion of the beds are hidden it seems reasonable to suppose that the structure observed is not interrupted in any way, in which case the quartzite is shown in its proper relation below the limestone series, and probably separated from it by an unmeasured thickness of shales. The small outcrop of quartzite near the road just south of the smelter is also indicative of the same relations, but the only conclusive evidence, aside from the analogy between the supposed sequence at Rico and the known succession of strata in the Animas region, is that furnished by the record of the drill hole given above. From this record it appears that a thick body of quartzite actually does occur beneath the limestone at about the distance estimated from the surface exposures. Some doubt is expressed concerning the strata between the quartzite and the limestone, since the complete sequence is nowhere exhibited at Rico in a single section, nor were shales noted above the quartzite by the person who made the record of the Atlantic Cable boring.

The quartzites which are so well exposed along the railroad on the north side of Silver Creek below the bridge have been referred to the Devonian on the map, but their age is somewhat questionable. They are evenly but rather massively bedded rocks, some bands being separated by thin calcareous shale layers, and one notable coarse quartzite

conglomerate stratum is exposed in the railroad cut. These beds strike N. 60° to 70° W., and dip about 30° in a direction west of south. This structure would carry them beneath the thin limestones and calcareous shales exposed by the South Park tunnel and penetrated by the Fate shaft. In the latter some of the thin limestones contain crinoid stems and unidentifiable shells, and appear to correspond to the basal strata of the Carboniferous, as known in the general Animas section and as actually seen on the west bank of the Dolores at Rico directly above the Devonian limestone.

To consider the quartzites in question as Carboniferous involves the assumption of a local development of pure quartzites below the ordinary base of the Hermosa formation, while the sandstones of that series are characteristically arkose in composition, containing much feldspar. To consider them as Devonian involves an explanation of the absence of the Devonian limestone which normally belongs above them. This might be accomplished by a north-south fault crossing between the Fate shaft and the quartzite exposures on the railroad, by which the limestone might be supposed to have been faulted up and removed by erosion. But in the South Park workings and apparently to the west of the possible line of such a fault very similar quartzites with a quartzite conglomerate are revealed beneath the Newman Hill porphyry sheet in about the position which the strata of the railroad cut would occupy if undislocated by such a fault as that hypothesized. It may be noted that a vein is exposed on the north bank of Silver Creek just above the South Park with the course assumed for this fault, but there is no means of determining the dislocation, if any, which has occurred on this vein fissure.

The alternative explanation for the nonappearance of the Devonian limestone above the quartzites of the railroad cut is that it had been removed by erosion in this locality before the deposition of the lowest Hermosa strata. Although no angular unconformity has been detected, as required by this explanation, the fact that Upper Carboniferous beds rest upon Devonian in the San Juan region and in the Dolores Valley at Rico shows that a great stratigraphic break does occur at this horizon, and this explanation is provisionally adopted as the most plausible under the circumstances. In discussing the faults of this part of Silver Creek (pp. 124-126) further details regarding this locality will be given.

These quartzites are supposed to be limited on the east by a fault separating them from a wedge-shaped area between the Smelter and Silver Creek faults, within which there are almost no exposures. It has been assumed that the fault is not great and that the Devonian beds have been dropped in that wedge, as is explained in another place (p. 125).

The relations of the assumed Devonian quartzites to the schists may

be studied near the northern limit of the Algonkian on either side of the river. On the east side, near the Nora-Lily tunnel, quartzite is seen only a few feet above exposures of the schist, and dipping about 45° N. In this vicinity the schists stand nearly vertical, so that it is evident that the quartzite was deposited upon their eroded edges, and that it is, therefore, Devonian, in accordance with the relations seen in the adjacent Animas region. Similar conditions appear to exist on the ridge west of Piedmont, though outcrops of the two formations are not seen close together in this vicinity. Elsewhere at Rico the lower part of the quartzite is not exhibited.

In both localities mentioned above, the schists underneath the quartzite are cut off on the north by an east-west fault, amounting to about 300 feet, by which the quartzite is dropped down, so that on the east side of the river its top and a few feet of shales above it are exposed about 50 feet above the railroad track. This is the central of three known parallel fault fissures about 100 feet apart, each of which throws the formations down to the north. These seem to represent a splitting of the Last Chance fault. By the northernmost the quartzite is entirely buried, while in the block between the southernmost and the Smelter fault the schists are raised an unknown amount. They are exposed at the Futurity tunnel 400 feet above the river, but the rocks are covered above that, and it is not known whether the Devonian quartzite is present in this block or not. On the west side of the river, above Piedmont, the surface materials still more effectually conceal the structure of this complicated area.

The exposures of the quartzite upon the Nora-Lily claim show a thickness of approximately 150 feet, but neither this nor the Atlantic Cable boring, which shows 170 feet of quartzite, gives the whole of the formation, since in the former the top is not seen and in the latter the bottom is not reached. It seems unlikely, however, that the total thickness is more than 200 feet.

The limestone.—The Devonian limestone, as it occurs at Ouray and in the Animas region, is made up of massive beds of limestone separated by thin intercalations of marl or shale. Certain thin bands are frequently quite coarsely crystalline, though this feature seems to be not due to metamorphism of the limestone, since the inclosing strata and the large mass of the formation is dense or semicrystalline limestone rather than marble. Fossils are usually to be found in some part of the series at any locality.

At Rico the Ouray limestone has been greatly metamorphosed. When pure, it has the coarsely crystalline structure of marble, and where originally somewhat earthy it shows now the presence of various secondary silicates, such as garnet, epidote, pyroxene, and possibly vesuvianite. Any fossils which may have occurred in them have been destroyed, so that the original character of the limestone is

entirely obliterated. This alteration is attributed to contact metamorphism connected with the intrusion of the monzonite stock on the west side of the dome. Similar effects are seen in the baked and metamorphosed strata of the Carboniferous, where they lie adjacent to the monzonite upon Darling Ridge. A very good idea of this series of strata may be gained from a study of the exposures along the west side of the river between the Shamrock tunnel and the wagon bridge above. The limestone is limited above by baked shales and sandy limestone containing Upper Carboniferous fossils. The uppermost bed of limestone, which is very much metamorphosed, is about 20 feet in thickness and is separated by a few feet of shales from a white crystalline bed about 25 feet thick, below which the strata are hidden for perhaps 60 feet, when another massive limestone is exposed, dipping, like the others, toward the south. The exposures opposite the bridge and just west of the road show thin bands of quartzite in metamorphosed shale, and these probably represent the lower limit of the limestone series, since massive quartzite is exposed a few rods toward the northwest in the bed of the river. The approximate thickness of the limestone series, as estimated from these exposures, is 150 feet, though this figure would seem to be under rather than in excess of the true thickness. Other exposures of the limestone reveal neither the structure nor the thickness of the formation, but it is probable that the outcrops on the Atlantic Cable claim and at several test openings above and to the east of the smelter belong to the uppermost of the limestone beds, since they show the same brecciated appearance that may be seen in the limestone at the Shamrock tunnel. In the boring of which the record is given on page 42, 120 feet of limestone were recognized, together with 20 feet of ore, which probably represents the replacement of an equivalent thickness of limestone. "Porphyrite" is also recorded to a thickness of 33 feet. The thickness measured across the beds would be somewhat less than the above aggregate of 173 feet, because the strata are not level but rise toward the north; but since the boring was started below the top of the limestone series, possibly 20 feet of limestone should be added, so that after subtracting the porphyry the thickness of the Devonian above the quartzite would be approximately 150 feet, which corresponds with the surface estimate given above. The structure exhibited by the limestone on the west side of the river, if continued toward the north, would carry the formation against the tongue of monzonite which cuts down the hillside south of the Montezuma mine. North of the monzonite it should again appear and fall successively toward the north, with the downward steps of the underlying quartzite. Unfortunately this slope is buried underneath surface débris, so that the actual relations can not be learned from such explorations as the geologist is able to command, and the presence of the limestone

must be taken as a suggestion rather than a conclusion. The same may be said for the probability of the limestone occurring above the quartzite on the east side of the river. In this case, however, its presence or absence could be determined by a small amount of excavation.

Economic importance of the limestone.—The importance of the Devonian limestone at Rico is of course centered about it as an ore-bearing horizon, and speculation concerning it in this rôle has evidently engaged some of those who have been interested in the mining industry of this region. This point is discussed by Rickard in his paper upon the Enterprise mine, where the evidence then available was taken as distinctly against the presence of any "second contact" beneath the "Newman contact" of the Enterprise and other mines of Newman Hill. The data upon which this opinion was based were mostly the records of shafts and borings which failed to show bedded ore bodies, or "blanket veins." It is evident from the structure exhibited by the geological map that the Ouray limestone has not been thoroughly explored on the lines where it is cut by the Smelter fault and minor fissures. But since it is highly mineralized in several places along the banks of the Dolores, carrying large bodies of heavy sulphides, it is seen to be a favorable horizon for the occurrence of ore bodies wherever it is cut by metalliferous veins. That it should be mineralized throughout its extent is, of course, entirely improbable, and it appears to be true that the sulphide bodies in it thus far developed are too low in silver contents to be of economic value.

It has been assumed, as above explained, that the limestone is probably absent in the vicinity of Silver Creek, above Rico, owing to pre-Carboniferous erosion, but it is to be hoped that future explorations will definitely settle this point.

CARBONIFEROUS.

The Carboniferous rocks of the United States have been divided into three groups: The Mississippian, or Eocarboniferous; the Pennsylvanian, or Carboniferous proper, and the Permian;¹ the further designation of Permo-Carboniferous² has also been used for strata which have faunal characters of an intermediate aspect.

While all of these divisions, except the true Permian, are known within the limits of Colorado, the invertebrate fossils characteristic of the Pennsylvanian occur in the San Juan region within 100 feet or less of the Ouray limestone, and the existence of the Mississippian in that region has not as yet been demonstrated.

In the Animas Valley and adjacent areas the Carboniferous strata have been divided into the Hermosa and Rico formations. The first

¹ H. S. Williams, Bull. U. S. Geol. Survey No. 80, 1891.

² F. B. Meek, in Rept. U. S. Geol. Survey of Nebraska and adjacent Territories, 1872, p. 132.

is correlated with the Upper Coal Measures because of its fossils, while the other is called Permo-Carboniferous, since its fossils are in part similar to those of the Carboniferous and in part like those of the Permian.

HER OSA FORMATION.

CHARACTERISTICS IN THE SAN JUAN REGION.

Definition.—Occurring between the Devonian limestone and the typical red beds, and sharply defined from each, there is a heterogeneous series of rocks which is generally distributed in the San Juan region, where it reaches a maximum thickness of about 2,000 feet. It is characterized throughout by a brachiopod fauna of Coal Measure age, thus corresponding with the Missourian stage of the Pennsylvanian series as it occurs in the Mississippi Valley. Some of the more common characteristic fossils are *Fusulina cylindrica*, *Productus semireticulatus*, *Productus nebraskensis*, *Productus cora*, *Spirifer cameratus*, *Chonetes mesoleobus*. This group of strata will be called the Hermosa formation, from the large creek of that name entering the Animas River in the Durango quadrangle. There are extensive exposures of the formation at many places in the drainage basin of this creek, the greater part of which lies in the Engineer Mountain quadrangle.

General description.—Lithologically the Hermosa is composed of limestones, shale, and sandstone, but all of these strata are more or less calcareous throughout. The limestones are of a blue-gray color, rather dense in texture, and usually very fossiliferous. They are frequently more or less bituminous, sometimes so much so as to afford a distinct odor of petroleum when struck with a hammer. The shales vary from black bituminous clay shales, rather fissile, to sandy shales and sandstones of an olive-green color. The sandstones are also of a greenish color, and under the microscope are seen to have an amorphous green cement, the composition of which is unknown. The materials of the sandstones are usually feldspathic and frequently micaceous; they vary in grain from fine to coarse, and are sometimes conglomeratic. The formation has a considerable distribution in the western part of the San Juan region, but throughout the area of its occurrence it is not in general divisible, since individual beds and groups of strata change greatly in character from place to place, so that horizons can not be definitely recognized in localities separated from one another by more than short distances.

Animas section.—The strata of the Hermosa formation form the western wall of the wider valley of the Animas outside the canyon, from Hermosa Creek to the drainage of Cascade Creek, and thence, still northward, their outcrops may be traced nearly to Silverton. In

this distance of 25 miles the variable and inconstant character of the formation is well exhibited. The fossiliferous limestones which occur at the base just above the Devonian are found throughout this extent, but the strata above them change greatly from place to place. Near Hermosa Creek the lower part of the formation above the limestones is made up of green sandstones and shales with some bands of gypsiferous shale; the middle and upper parts show fossiliferous gray limestones in beds from 1 to 20 feet in thickness, interbedded with shales and sandstones. Northward from this region the limestones become more massive and the intercalated shales and sandstones less important, so that for some distance south of Cascade Creek the limestones of the middle section are very prominent, forming the upper scarp of the valley wall. The upper massive limestones extend westward nearly to Hermosa Park, and here the upper part of the Hermosa formation is seen to have some fossiliferous limestones within the shale and sandstone series. The lower portion of the Hermosa is not well exposed, but important limestones are certainly not common in it above those which lie upon the Devonian. Gypsum has not been found north of the Durango quadrangle, though it may be present and undiscovered because hidden from view by surface debris. Between Lime Creek and Molas Lake the Silverton wagon road traverses the Hermosa formation, and in this vicinity it exhibits a distinct phase, since the blue fossiliferous limestones are less massive than to the south and are distributed throughout the entire thickness of the formation.

The variable character of the Hermosa, as shown in the preceding paragraphs, is indicative of the unity of the formation, and this is further borne out by the invertebrate fauna as a whole, which Mr. Girty finds it impossible to divide into subfaunas. No division can be made which will have other than local value.

DESCRIPTION AND DIVISION OF THE RICO SECTION.

General statement.—At Rico the Hermosa formation has about its normal development, since it reaches a thickness of 1,800 feet or more. It shows an unmistakable general correspondence to the Animas section, and in particular has a development similar to that in the adjacent portion of the Animas region, where the limestones in the medial portion of the formation are massive and conspicuous. At Rico, however, the gray or blue limestones are even more closely segregated in the middle third of the formation, and are of rare occurrence in the upper and lower portions. This is doubtless entirely a local facies of the formation, as may be inferred from the facts cited in the discussion of the Animas section, but it makes it possible to divide the Hermosa, as is shown at Rico, into three approximately equal parts, and this division will be followed in description. Upon the detailed geological map of the

Rico Mountains the upper member has been represented by a distinct pattern, in order better to exhibit the structure, but the two lower members have not been separated. This division is made simply as a matter of convenience, as there is no intention of raising the divisions to the rank or importance of formations.

Lower division.—The lower division is about 800 feet in thickness, excluding the porphyry sills which have been intruded between its strata. At the base and resting upon the Devonian limestone there are shales and impure limestones which have been considerably baked and metamorphosed, but which may still be seen to contain abundant Upper Carboniferous fossils, and which correspond with similar strata occurring above the Devonian along the western side of the Animas Valley. Above this the rocks are green or gray grits, or sandstones, alternating with gray shales and containing several beds of black shale and occasional thin impure limestones. The ore-bearing horizon of Newman Hill, known as the "contact," is associated with one of the black shales which occurs about 450 feet below the massive limestone series which forms the lower part of the upper division of the Hermosa. A bed of rock gypsum, sometimes reaching a thickness of 30 feet, occurs locally above the black shales of the "contact" series, and was probably more widely distributed originally, since wherever it has been seen there is evidence that it has been attacked by circulating waters and in part removed by solution. Above this is an interval of 250 feet which is nowhere exposed to view, followed by 200 feet of massive and flaggy sandstones constituting the uppermost strata of the lower division.

Exposures of the lower beds.—Containing as it does the Newman Hill "contact," and at least one other ore-bearing horizon, knowledge of the lower division of the Hermosa formation at Rico becomes important in the study of the geological features of the ore deposits. However, its strata are so much hidden by surface materials that, even with the aid of sections revealed in mine workings, only the most general idea of the sequence of strata has been gained. In what follows it is intended to indicate as closely as possible the position in the formation of the beds that are to be seen at the different localities mentioned.

Underneath the superficial materials of varied origin which cover the lower slopes of the Dolores Valley, the lower part of the Hermosa formation occurs as an incomplete or interrupted elliptical band surrounding the town of Rico and the area of older rocks outcropping just to the north of the town.

The fossiliferous limestone marking the base of the formation is found above the Shamrock tunnel, where its relation to the Devonian is apparent, but aside from this locality no other outcrops are known.

Incomplete knowledge of the Devonian series, as well as of the

Hermosa, and the extremely complicated structure in the valley of Silver Creek, precludes positive statement as to the horizon of all the beds which outcrop in that vicinity. There is some reason for supposing that the calcareous shales exhibited north of Silver Creek, near the South Park tunnel, and which may be seen lying conformably upon the quartzite in the vicinity of the Fate shaft, belong between the quartzite and the limestone of the Devonian, but there are other facts which seem to indicate that they belong to the lower part of the Hermosa, and though the matter is still in doubt, they have been represented on the map as belonging to the upper formation. Concerning the black shales which are exposed in the railroad cut just south of where the Silver Creek wagon road crosses, there is less doubt. They belong to the lower part of the Hermosa, and with them must be placed the strata which have been revealed in the various tunnels and shafts in this vicinity.

The character of the sandstones which occur in the lower 200 feet or so of the formation may be seen along the Enterprise road near the city limits, and in the strata traversed by the Hibernia tunnel on the south side of Silver Creek. In both places massive green sandstones and gray shales are to be seen. The only other exposures of Hermosa strata which are definitely known to lie below the horizon of the thick porphyry of Newman Hill are those in the lower part of Allyn Gulch, where several prospects have revealed sandstones and black shales.

The thick porphyry sheet which has been intruded into the sediments, and which has been mapped upon the north side of Newman Hill, reaches a thickness of about 500 feet, as indicated in the boring of the Skeptical shaft, and by the known occurrence above the shaft, but before reaching the west side of the river it seems to have thinned out or split into several sheets. For this reason it has been impossible to correlate the strata associated with porphyry at several places west of the river with those above the porphyry on Newman Hill.

Immediately above the sheet there is a black shale, as seen at the New Year mine on Newman Hill, and other indications of black shales in this part of the section are seen in the materials which were raised from the shaft just north of the cemetery and in the tunnels and stopes of the Hunter mines, on the west side of the river.

On Newman Hill definitely known strata of this lower division are exhibited in the workings of the Enterprise mine and in the shaft below the main level of the Union Carbonate mine. These sections show an alternation of gray or green sandstones and grits in beds from 3 to 20 feet thick, with gray shales of like development to an aggregate thickness of approximately 110 feet. Above this series at both places comes the ore-bearing complex composed of dark shales and limestones, and at its base there is another black shale about 15 feet in thickness. This correspondence, taken with the general struc-

ture, is considered as strong evidence that the ore horizons of the two mines are identical. The lower portion of the Union Carbonate shaft was not accessible at the time the section was made, but it is reported that a third black shale was encountered at the bottom of the shaft, about 90 feet below the one mentioned above. Considering the nature of the strata which go to make up the formation, the black shales are apt to be the most constant horizons in the series, and while sandstones and other shales may lose their thickness and disappear, these may be safely used for purposes of correlation in so limited an area as the Rico region, when their relative position is once established. The exposures south of the Group tunnel, near the Newman mines, belong to this same general series below the "contact" shales. In several places in the Enterprise mine the rocks associated with the ore-bearing horizon are overlain by an irregularly intruded porphyry sheet from one to several feet in thickness. The black-shale series immediately below the porphyry has the constitution shown in the following section (from top downward), taken in the vicinity of Jumbo No. 2 vein near raise 13:

Section in vicinity of Jumbo No. 2 vein, Enterprise mine.

	Ft. in.
7. Shale, black, somewhat brecciated.....	3 0
6. "Contact," consisting of gray pulverulent marly material, sometimes structureless and sometimes stratified; frequently impregnated with silica, and varying in thickness from 1 to 2 feet.....	1 10
5. Limestone, dark and impure, breaking with vertical fracture; locally known as "short lime".....	1 5
4. Black, fissile shale with occasional lenses of gray sandstone in the upper part.....	5 0
3. Limestone similar to the "short lime," but very black with gash veins of quartzite.....	1 6
2. Shale, dark gray.....	1 6
1. Sandstone.....	8 0
Total.....	22 3

In parts of the Enterprise mine a bed of rock gypsum is found to occur above the black-shale series, sometimes reaching a thickness of 30 feet. Its presence is noted also in the Rico-Aspen workings, where, at the bottom of the Silver Glance shaft, the following section (from top downward) was studied:

Section in Silver Glance shaft.

	Ft. in.
14. Gypsum, 2 to 4 feet.....	4 0
13. "Contact" as in the Enterprise mine.....	1 2
12. "Short lime".....	0 11
11. Black shale.....	0 8
10. Friable sandstone.....	1 1
9. Shale and black limestone.....	1 9
8. Gray sandstone.....	0 9
7. Black shales.....	1 2

	Ft. in.
6. Black shale and limestone in alternating bands from one-half to 1 inch thick	1 8
5. Dense limestone of gray color with many gash veins	1 7
4. Black shale	2 1
3. "Short lime," black	0 6
2. Black shale	2 0
1. Gray sandstone	20 0
Total	39 4

The occurrence of heavy beds of gypsum associated with black shales and blocky bituminous limestones in the Animas region¹ in the corresponding part of the lower Hermosa formation, together with the massive character of the gypsum rock as observed at Rico, is strong evidence for accepting the deposit as an original part of the formation rather than as of secondary origin through the action of sulphuric solutions upon limestone, as proposed by Rickard.² At Rico the gypsum is only locally present, though whether its absence is due to nondeposition or to removal by solution can not be stated. Gypsum is perhaps the most soluble rock of ordinary occurrence aside from salt, and in the Rico-Aspen mine it is seen to be pitted and corroded, showing that circulating waters have been at work upon it there. If the gypsum was originally deposited throughout the region where the "contact" has been explored it is possible that the peculiar gray marly material, of which the latter is composed, may represent the insoluble residue of the gypsum which has been carried away.

Above the "contact" for a distance of 250 feet, or thereabouts, the character of the rocks is nowhere exhibited at present, for though this interval has been penetrated by several of the shafts on Newman Hill there is no record of their sections. Above this the uppermost 200 feet of the lower division of the Hermosa formation is composed almost entirely of green sandstones in massive and flaggy layers, but with only minor partings of shale. These sandstones are well exposed on the south side of the lower part of Deadwood Gulch, and again their upper layers are exposed below the faults in Deadwood Gulch and back of the Laura mine house. They are also shown in part on the north side of Horse Gulch below the cliffs of Sandstone Mountain near the wagon road, and probably also in other isolated outcrops where their relations can not be recognized.

Medial division.—The second division of the Hermosa is made up very largely of blue bituminous limestone, carrying many fossils and occurring in massive beds from 5 to 100 feet in thickness, separated by shales and sandy shales. In the lower part there are some intercalated strata of green sandstone and green or black shales, and locally these continue through the series, separating beds of limestone which

¹ Vide, p. 49.

² T. A. Rickard, Trans. Am. Inst. Min. Eng., Vol. XXVI, p. 970.

elsewhere lie close together. The medial or limestone member has a thickness somewhat in excess of 600 feet and is a prominent feature in the stratigraphy of the region. Its structure and general relations are exhibited in the illustration of Dolores Mountain (Pl. III), where its white ledges are shown; and in Deadwood Gulch, whence it passes above Newman Hill with a gradual rise toward the north, as seen on Pl. V. The massive limestones continue across Allyn Gulch, as shown on Pl. IV, partly covered in the vicinity of the stream, but appearing on the east side of the gulch near the Maggie trail and continuing until cut off by the Blackhawk fault, by which they are buried to a depth of several hundred feet. Upon the surface the top of the series is seen at the Blacksmith level of the Blackhawk mine, dipping rapidly from the northeast side of the fault toward Silver Creek. On the west side of the fissure the limestones appear in the road near the Argentine shaft, and from this place occupy a band between the Nellie Bly and Last Chance faults, in which the lines of stratification may be seen to rise rapidly across the steep hillside. On the west side of Nigger Baby Hill they are cut off by the profound displacement of the Nellie Bly fault, and in the block north of this fracture no outcrops of the formation occur.

Upon C. H. C. Hill the limestones are again present, occupying a position elevated with respect to the block immediately to the south, though the exact location and nature of the fault by which the strata have been raised have not been ascertained. In this region the rocks are not well exposed, being covered by large amounts of surface débris and obscured by surficial landslides. The bedded deposits of pyrite which have been encountered in several mines upon this hill probably occur within this limestone series.

The massive limestones are well exposed by the cutting of the river south of Burns, and from this place rise rapidly into the cliffs of Sandstone Mountain, where all but perhaps 100 feet of the series is exposed. The occurrence of these strata is illustrated on Pl. VI, which is a view of Sandstone Mountain from the east. The limestones are here less massive than in the face of Dolores Mountain, seldom reaching a thickness of 25 feet, as opposed to beds of uninterrupted limestones 60 to 100 feet in thickness in the latter place, but the upper limit of the series is definitely recognizable in both places at the base of a homogeneous bed of light-colored calcareous sandstones and marls nearly 100 feet in thickness. The following section of the strata exposed in Sandstone Mountain, from near the top of the Hermosa to the lowest exposures not far from the base of the central division, was studied by Mr. Cross. In the saddle of the long ridge above the 10,400-foot level, the base of the Rico formation crosses, with its characteristic fossil limestones, below which the *Fusulina* layer is exposed; but below this the con-

tinuity of the section is broken by a fault, raising the strata toward the south. The section begins below the fault.

Section (from top downward) in Sandstone Mountain.

	Feet.
54. Coarse grit, rather thinly laminated.....	10
53. Dark-red sandy shale, with very smooth, undulating partings.....	5
52. Sandy limestone, containing nodules and lenses of pure limestones.....	5
51. Massive sandstone, gray in the lower part and red above; this stratum forms the knoll above the 10,450-foot contour.....	20
(<i>d. Porphyry</i> , 25 feet.)	
50. Gray and green sandstone of medium coarseness, with rather distinct bedding, occurring in two bands separated by a shaly parting.....	30
(<i>c. Porphyry</i> , about 30 feet.)	
49. Massive grit.....	8
48. Red, sandy, and micaceous shale, weathering into thin flakes.....	5
47. Grit and conglomerate; the upper 5 feet is of medium grain and laminated, while the lower 15 feet is massive, and it is made up of quartz and orthoclase with quartzite and granite pebbles distributed through it.....	20
46. Shaly sandstone with calcareous nodules in the upper part.....	6
45. Massive gray sandstone, grading upward into No. 46.....	18
44. Dull-red shaly sandstone.....	3
43. Massive gray sandstone, grading upward into No. 44.....	12
42. Calcareous shales and sandstones of a red or pink color, containing nodules or lenses of gray, often bituminous limestone.....	35
41. Massive sandstone or grit containing some pebbles.....	7
40. Calcareous shales and sandstones of a light color.....	20
39. Fine and even grained sandstones of a gray-green color, with occasional shaly partings.....	25
38. Black shales, mostly very thin bedded and fissile, containing bands of bituminous limestone, which, when pure, is of a rough, coarse texture, but when sandy is hard and laminated; the limestone layers contain crinoid stems and shells.....	77
37. Gray or green massive sandstone, very hard and of medium grain.....	6
36. Sandstones and sandy shales.....	3
35. Light-gray sandstone and calcareous shale in alternating beds, from a few inches to 2 or 3 feet in thickness and containing some layers of nodular limestone.....	32
34. Sandy shale of a hematite-red color.....	15
33. Greenish-gray calcareous sandstone of medium-coarse grain, forming a prominent but thin-bedded series.....	22
32. Blue-gray limestone; somewhat shaly in the lower part, but massive above and richly fossiliferous throughout.....	7
31. Coarse-grained sandstone with a calcareous cement.....	12
30. Calcareous and bituminous sandstone.....	3
29. Blue bituminous limestone, rather coarsely crystalline.....	3
28. Greenish-gray massive sandstone of medium-coarse grain, and having a calcareous cement.....	13
27. Black, carbonaceous, somewhat sandy shales, containing thin bituminous limestone bands, some of which contain many fossils.....	40
26. Green or gray sandstone of a fine-grained, close texture.....	1
25. Dark sandy and calcareous shale.....	5
24. Light-gray thin-bedded sandstones, calcareous in part.....	20
23. Sandy and calcareous shales, partly dark and partly light-gray; some of the strata contain many brachiopod shells.....	24

	Feet.
22. Blue-gray massive and fossiliferous limestone.....	3
21. Calcareous shales and thin-bedded sandstones of a light-gray color, forming an indivisible series.....	95
20. Gray massive limestone, containing corals.....	6
(b. Porphyry, about 75 feet.)	
19. Rather thin-bedded limestone made up very largely of crinoid stems, but containing also some other fossils.....	15
18. Green-gray or reddish sandstone, massive and calcareous in the upper part and alternating with sandy shale near the base.....	36
17. Blue limestone of a dense texture.....	3
16. Greenish-gray dense, but thin-bedded sandstone.....	35
15. Limestone, massive in the lower part, but wavy bedded near the top; contains many crinoid stems.....	7
14. Green fine-grained sandstone, rather thin bedded, but forming a prominent outcrop.....	16
13. Blue-gray limestone, rather massive, but wavy bedded near the top; this layer contains many crinoid stems.....	12
12. Medium to fine-grained sandstones, for the most part thin bedded or shaly, but with some massive layers.....	30
11. Blue or dark gray fine-grained sandstone, very thin bedded or shaly.....	46
10. Blue-gray fossiliferous limestone, made up of wavy layers 2 to 3 inches thick.....	14
(a. Porphyry, 5 feet.)	
9. Gray, medium-grained and thin-bedded sandstone; very friable in part..	20
8. Shaly sandstone with a calcareous cement having an irregular fracture; color, usually dull red, but sometimes greenish.....	21
7. Massive gray sandstone, arkose in character and of medium coarse grain.	3
6. Dull-red sandy shale.....	3
5. Light-gray limestone of a dense texture, with a few crystals of calcite disseminated throughout the mass; this stratum is nodular in the lower part, and to some extent throughout its thickness, and it contains a few corals.....	2
4. Sandstone, partly laminated and partly massive; the laminated portions are red, while the more massive portions are green.....	10
3b. Limestone, rather thin bedded, occurring in wavy bands from a few inches to a foot in thickness; this stratum has a conchoidal fracture which passes through the shales and crinoid stems contained in the limestone; under the action of the weather its surfaces become rough and prickly.	20½
3a. Similar to 3b, but in addition the weathered surface shows a peculiar mottling because of dense parts outlined by dark curved lines of coarsely crystalline calcite, which in weathering stand out as projecting ridges..	2½
2. Purplish-red shaly sandstone; this stratum is in part hidden, but seems to be made up of a fine-grained, crumbling calcareous shale in which limestone nodules are also present.....	15
1. Blue-gray limestone, massive in the lower part, but rather thin bedded in the uppermost 3 feet, where it carries lenses of chert; this limestone contains crinoid stems and a few brachiopod shells; it weathers with a rough surface.....	21
Total.....	938

The medial division of the Hermosa includes all the strata of the above section from the base up to and including No. 20 of the section. The strata above No. 20 belong to the upper division of the formation.

In Papoose Creek limestones are well exposed, and in the vicinity of the Puzzle mine are to be seen in the mine workings and also in surface exposures. Farther to the west, upon the south side of Horse Gulch, the limestones have been baked and metamorphosed and at present show a marbleized condition and the presence of pyroxene and garnet. The exposures in this region are very poor, but the rapid rise of the strata toward the south may be made out, and enough may be seen to show that this series runs around into Iron Draw, connecting with the exposures which may be seen in the cliffs in the vicinity of the Zulu Chief mine. In this region they are also locally metamorphosed, undoubtedly by the stock of monzonite of Darling Ridge. Elsewhere on the west side of the river the main mass of limestone is nowhere exposed in place, unless the blocks which occur on the river bank south of the Silver Swan mine are outcrops in situ. However, there is strong evidence that they form a part of a large landslide mass which has come down from the slopes above. The series is without doubt present under all the surface débris in the slopes south of Sulphur Creek, but so deep is the mantle of loose material that all the formations are effectually hidden as far to the south as Burnett Creek.

Upper division.—The upper division of the Hermosa, which is mapped separately, contains some bands of limestone similar to those of the medial division, but they are thin and unimportant in comparison. Its strata are mainly black and gray shales alternating with green grits and sandstones. Occasional reddish sandstones are observed, and two black shales are present in the lower third of the division. The top of the upper division, and of the Hermosa formation as a whole, is well defined from the base of the next higher formation. The topmost member consists of about 30 feet of fine-grained mica-bearing green shales, immediately above which comes a red, sandy, fossiliferous limestone of the Rico beds. At the base of this shale a band of blue limestone, usually from 6 inches to 1 foot in thickness, is always present, and this stratum is characterized by the minute spindle-shaped shells of *Fusulina cylindrica*, a fossil which is not known to occur above the Pennsylvanian Carboniferous. The upper portion of the Hermosa is of less importance from an economic standpoint than either of the lower members, but in order that the basis of separation of the Hermosa and Rico formations may be easily studied upon the ground, some localities may be mentioned where the *Fusulina* limestone is to be seen, and where its relations to the fossil-bearing strata of the higher formations may be observed.

In the steep slopes of Dolores Mountain on the west the *Fusulina* layer may be seen at various places just below the change of color from green to red which marks the line between the upper Hermosa and the Rico strata. In this region the fossiliferous bands of the latter formation are also well exposed.

The following section of the upper beds of the Hermosa formation was studied on the south side of the gulch back of the Laura shaft, on the west slope of Dolores Mountain. The top is just below the lowest fossiliferous sandy limestone of the Rico formation.

Section (from top downward) on Dolores Mountain.

	Feet.
26. Green fissile shale	6
25. Green micaceous shale, irregularly bedded, sparingly fossiliferous, with crinoid stems.....	10
(b. Porphyry, 10 feet.)	
24. Crumbling green shale, containing very few fossils	15
23. Fusulina limestone.....	$\frac{1}{2}$
22. Green shale	2
21. Crumbling green shale	4
20. Coarse arkose sandstone, cross bedded, gray.....	6
19. Red sandstone and earthy limestone and calcareous shale	10
18. Dark-red sandstone, micaceous, containing nodules of black limestone...	6
17. Red and gray crumbling shale	9
16. Red sandstones, micaceous	5
15. Arkose sandstone, micaceous, containing some small pebbles, rather coarse as a whole, gray	15
14. Micaceous sandstones, grading into gray and red earthy limestones.....	15
13. Sandstone, micaceous and flaggy, red.....	25
12. Green shales, fissile in part, also micaceous; near the bottom of the series there is a thin bituminous limestone, commonly composed of comminuted shells	22
11. Arkose sandstone, gray.....	15
(a. Porphyry.)	
10. Red shaly sandstone and gray conglomerate alternating	40
9. Gray earthy limestone and micaceous sandstone	20
8. Series of red and green sandstones, somewhat arkose, with a 4-foot sandy limestone, 25 feet from the top.....	35
7. Not well exposed, but probably green Carboniferous sandstone	25
6. Black shale, with fossiliferous limestones near base, containing <i>Productus</i> and other fossils	30
5. Limestone, gray, somewhat sandy, contains much comminuted shell material	3
4. Sandstone, fine grained, red in the lower part	6
3. Limestone, earthy, more or less marly, not distinguishable from the limestone of the Dolores formation	12
2. Covered, probably red, micaceous sandstone.....	10
1. Sandstone rocks of a medium and uniform grain, cross bedded, green.....	20
Total	354 $\frac{1}{2}$

Below this section the strata are displaced by a fault, and can not be identified in their relation to the beds exposed above.

The characteristic strata at the top of the Hermosa may be seen again in the lower part of Uncle Ned Draw, where they serve as an accurate guide in determining the amount of faulting upon the Uncle Ned fissure, which is a direct extension of the Blackhawk fissure. They are also to be seen in the high cliffs northeast of C. H. C. Hill and

just north of Marguerite Gulch. They have been found on the ridge west of Papoose Creek, but have not been discovered in the region between this and the ridge north of Burnett Gulch. In this last place they are very poorly exposed, but cross the ridge in the vicinity of the 10,600-foot contour. On the south side of Burnett Creek they are again exposed. The line which has been drawn on the map to represent the top of the Hermosa formation may be taken as a guide in searching for these characteristic horizons.

A typical section of the upper division of the Hermosa as it occurs in Sandstone Mountain has been given on page 55, but this section does not include the highest layers of the formation. Possibly 75 feet of strata may have been let down by the fault which crosses the ridge south of the base of the Rico formation, and no good outcrops could be found to show the local character of this part of the section.

FOSSILS AND CORRELATION.

Organic remains are numerous and well preserved in the Hermosa formation. By far the larger number are brachiopods, though gastropods occur, and also the characteristic foraminifer *Fusulina cylindrica*. Most of the species are identical with forms occurring in the Missourian stage of the Carboniferous of the Mississippi Valley, which corresponds in point of age with what is commonly known as the Coal Measures. The same assemblage of organic forms is found at various places in Colorado. In the Gunnison region similar fossils are found in the Weber and Maroon formations, as described in the Anthracite-Crested Butte folio of the Geological Survey, showing that the Hermosa comprises the former and part of the latter formations. It also probably represents all of the Aubrey series of the Plateau and Grand Canyon regions, though conforming more precisely with the description of the upper portion than of the lower.

The detailed studies which have recently been made of the sedimentary rocks of the San Juan region have led to a grouping of the Carboniferous and of the red portion of the Juratrias quite different from that employed by the Hayden Survey. Reference to the Hayden Atlas of Colorado will show that the strata between the Devonian and the Jurassic sandstone (corresponding to the La Plata) were mapped as Middle and Upper Carboniferous. The mapping of the former division corresponds in general with the occurrence of the Hermosa formation, leaving the latter as the equivalent of the Rico and Dolores formations.

RICO FORMATION.

Definition.—It is here proposed to apply the name Rico to a formation assumed to be about 300 feet in thickness, occurring between the Hermosa or characteristic Pennsylvanian Carboniferous and strata

assigned at present to the Trias of the San Juan region—the Dolores formation. It is made up of sandstones and conglomerates with intercalated shales and sandy fossiliferous limestones. In its lithological features it resembles the strata immediately above it, but its fossils are distinctly of Paleozoic age, and while many of its forms are common to the Hermosa formation, others are of Permian type, so that it seems proper to designate its age Permo-Carboniferous, to indicate that it is transitional between these divisions of the Carboniferous system. In the Rico region the formation is conformable upon the Hermosa and is followed by the Dolores with seemingly perfect parallelism of stratification. The fauna as a whole has an aspect quite different from that of the Hermosa, since it is largely composed of lamellibranchs as opposed to the brachiopod assemblage of the lower formation. The boundary between the Rico and Dolores formations is at present entirely artificial, being based upon the highest known occurrence of the Rico fossils. The former is made to include only strata characterized by the Rico fauna, while the latter comprises the apparently unfossiliferous medial portion of the Red beds together with the upper part, of known Triassic affinities. The actual age of the unfossiliferous Red beds is thus left in doubt; they may eventually prove to be either Permo-Carboniferous, true Permian, or Trias. They correspond to what has been called Trias throughout the Rocky Mountain province.

Discovery of the formation.—The Rico formation was first recognized as distinct from the Red beds which lie above it during the field season of 1898. Its fossils were first collected in the vicinity of Hermosa Park, and were afterwards found in the lower part of Scotch Creek, a tributary of the Dolores at the southern base of the Rico Mountains. At this place its well-exposed strata are abundantly fossiliferous, and from them were collected the larger part of the material from which the age relations have been determined by G. H. Girty. The Scotch Creek section is given on page 62.

Description.—The general characteristics of the Rico formation in the vicinity of Rico are, first, its calcareous nature, in which it resembles the strata above and below; second, the very arkose character and the coarseness of its sandstones, in which respect it differs from the Hermosa and resembles the Dolores; and, third, its chocolate or dark-maroon color, which contrasts sharply with the gray or green of the Hermosa and which is more or less distinct from the bright vermilion of the Dolores. Locally, through metamorphism, the deep-red color has been changed to green, as seen in the cliff exposures north of Silver Creek, in the vicinity of the Uncle Ned Draw, and in the cliffs exposed on the northern slopes of Dolores Peak.

The bulk of the formation is made up of sandstones and sandy shales composed of such materials as are derived from the disintegration

of granite. The sandstones are mostly coarse or conglomeratic, always showing grains of fresh feldspar mixed with mica flakes and quartz. When conglomeratic the pebbles are chiefly of schist and quartzite. The coarser sandstones are usually cross bedded and occur in massive beds from 2 or 3 to 25 feet in thickness. Some of the coarse sandstones are of very much lighter color than the mass of the formation. When fine grained the sandstones are usually somewhat laminated and pass into sandy shales. The shales, aside from the sandy varieties, are of two kinds—the fine-grained, unlaminated, red, marly beds, similar to those of the Dolores, and the equally fine-grained laminated clay shales of a green color.

Intercalated with the sandstones and shales, which are for the most part very calcareous throughout, there are several beds of impure limestone, some as earthy gray, sometimes nodular bands associated with the marly shales, and others as sandy limestone of a red color in strata from 6 inches to 2 feet in thickness. The latter and a 6-inch layer of limestone, which was taken as the upper limit of the formation in Scotch Creek, are very fossiliferous. The sandy fossiliferous bands have a characteristic appearance wherever they are found, since the fossils are preserved in white calcite, in sharp contrast to the red matrix of calcareous sand. They are found in the lower third of the formation, and while some of them are of local development and may be seen to grade both vertically and horizontally into the sand rock with which they are usually associated, at least one band is known to be persistent in the Rico region, and its equivalent has been recognized in those parts of the San Juan where its horizon has been studied. This fossiliferous band thus becomes diagnostic of the Rico formation, and is especially valuable in the study of the stratigraphy of the region, since it occurs within a few feet of shales which contain Hermosa fossils. At Rico its position varies little from 30 feet above the *Fusulina* limestone of the Hermosa formation, from which it is separated by green micaceous shales carrying shell fragments and crinoid stems, and is thus a reliable guide in defining the two formations. The formation is without any definite limit at the top, since the rocks which follow immediately above the highest known fossil-bearing beds are similar in every respect to the strata of the lower series; nor is it possible to apply the change in color as a criterion, except in a very general way; so that it has been found necessary to assume the thickness of the formation as equal to the greatest known thickness between the base and the uppermost fossils. In Scotch Creek the thickness on this basis would be 237 feet; on the north side of Silver Creek, near the Uncle Ned Draw, it would be about the same, but on the south slope of Nigger Baby Hill it is more than 300 feet. In drawing this upper boundary on the map the formation has been represented as about 325 feet in thickness.

The measured section taken in the lower part of Scotch Creek, which is given herewith, illustrates the features brought out in the foregoing description:

Section (from top downward) of the Rico formation on Scotch Creek.

	Feet.
22. Two fossiliferous limestones, each 6 inches to 1 foot thick, and separated by about 3 feet of green shale.....	4
21. Poorly exposed slope, containing several thin beds of light-colored sandstone, and in the upper part red sandy shale	20
20. Arkose sandstone, rather coarse, and containing some pebbles up to 1½ inches in diameter; pink.....	7
19. Shale and thin-bedded sandstone.....	7
18. Earthy limestone, unfossiliferous.....	1
17. Shales, forming a slope with a few thin bands of fine-grained sandstone; gray, green, and red	18
16. Massive arkose sandstone of a red color, quite conglomeratic in the middle, and resting upon a pink arkose conglomerate 2 feet thick.....	22
15. Crumbling shale, containing nodules of gray limestone; red.....	20
14. Sandy fossiliferous limestone; red.....	2
13. Series of variable sandstones; in the upper part the sandstone is thin bedded and alternates with shale; in the lower part the sandstones are of coarser grain; one layer showed probable worm borings; dark red, except for a few gray streaks	27
12. Gnarly limestone, earthy in the upper part.....	4
11. Friable sandstone and thin shale layers; dark red	15
10. Thin-bedded sandstone, passing downward into massive arkose sandstone and conglomerate; reddish.....	16
9. Crumbling shales of a dark-red color, containing band of gnarly limestone in the middle part	10
8. Arkose sandstone and conglomerate, pink or white, 2 to 3 feet.....	3
7. Micaceous calcareous sandstone and shining shales; dark red.....	3
6. Fossiliferous limestone, 1 foot to 15 inches.....	1
5. Micaceous sandstone, showing poikilitic structure, and containing some fossils; the upper part is rather massive; the lower part rather thin bedded and shaly	9
4. Fossiliferous limestone, 18 inches to 2 feet.....	2
3. Heavy micaceous sandstone of alternating red and gray colors, sometimes variegated; this contains a 12-inch layer of red, sandy, fossiliferous sandstone about 8 feet from the base, but grades up to a similar fossiliferous band 18 inches thick into a reddish, somewhat shaly sandstone about 10 feet thick.....	20
2. Micaceous sandy shale of a dark-red color	20
1. Sandy limestone, very fossiliferous, grading downward into gray flags	6
Total thickness exposed.....	237

Immediately below the lowest fossiliferous limestone there are micaceous calcareous shales, carrying a few shell fragments, in a thickness of 25 feet and representing the topmost beds of the Hermosa formation.

Local distribution.—The Rico formation is shown on the map as a band encircling the Hermosa formation except in those portions of

the area where it is hidden by surface débris. The base of the series is easily recognized wherever it outcrops; it may be seen on the ridge south of Deadwood Creek at the 10,450-foot contour, and again appears in the stream bed at the 10,550-foot contour, and again upon the southwestern shoulder of Dolores Peak, and from here may be traced with practical continuity to the ridge west of Allyn Gulch. Its position was accurately located on the east side of the knob between the forks of Allyn Gulch, but just east of this it is buried by the Blackhawk fault. However, it is again discovered in the vicinity of the Leila Davis mine, dipping steeply to Silver Creek, and appears from underneath the talus just east of Uncle Ned Draw at 10,025 feet. Here the relations of the Fusulina layer and the sandy limestones at the base of the Rico formation are well shown on the east side of the ravine in the lowest exposures. Upon the west side they are also discovered about 85 feet higher up, having been raised by the fault which follows the ravine. In this vicinity there are two fossil limestones less than a foot in thickness at the base of the Rico. The upper has the usual sandy character and forms part of a sandstone ledge; the lower, however, is quite free from sand and occurs as a distinct and very fossiliferous stratum in green sandy shales. Of these last there are from 3 to 5 feet between the two limestone bands and 35 feet underneath the lower and above the Fusulina layer. The boundary may be traced across Nigger Baby Hill, rising gradually until cut off by the Nellie Bly fault near the nose of the ridge. On the west side of the hill its presence is marked by the outcrop of the Hope vein, which, with the other veins that outcrop upon this slope, lies in the line of the stratification of the rocks. The proof of this statement may be seen in the occurrence of Rico fossils above the Hermosa beds near the Hope tunnel, where the apex of the vein is about 30 feet above the tunnel level, and in the fact that the Hope vein has been traced by the writer by means of the Hope and Phoenix workings from its outcrop to the Nellie Bly fault and found to lie in the line of stratification all the way. A short distance north of the Hope mine the rocks are hidden by surface materials and the Rico formation is not again recognized until the cliffs north of C. H. C. Hill are reached. Here the basal strata may be clearly seen, cut by several minor faults and descending steeply to the river, where they are again well exhibited in Marguerite Gulch. Not actually exposed on the slopes above Burns, they reappear on the flat ridge of Sandstone Mountain above the 10,400-foot contour, and again on the ridge west of Papoose Creek at an elevation somewhat lower. In the western half of the mountains they are not again recognized north of the southeast ridge of Expectation Mountain, where fragments were found upon the surface on the southern slope above 10,500 feet. On the south side of Burnett Creek the base of the formation is found

about 150 feet above the lowest thick porphyry sheet, which position it is assumed to hold to the limits of the area represented by our map.

As thus traced and as exhibited on the map, the Rico formation brings out the main structural features of the Rico Mountains, and in several instances has been the key to the measurement of the faults which cut the strata. So far as now known, the only place where the formation has been the country rock for valuable mineral veins is upon Nigger Baby Hill, north of the Nellie Bly fault.

Correlation.—That strata related to the Permian of the Mississippi Valley should be found in the southwestern part of Colorado might naturally have been expected from the occurrences of such strata in the surrounding regions. Fossils of Permian affinities were found by the geologists who accompanied several of the military and railroad expeditions which traversed the Rocky Mountains and adjacent regions from the early fifties on. From New Mexico Permian fossils were reported as early as 1858 by B. F. Shumard.

In 1875 Mr. G. K. Gilbert,¹ in a description of the Paleozoic formations of the Plateau region, noted the occurrence in the upper part of a series of strata having Upper Carboniferous affinities of certain fossils which suggested the Permo-Carboniferous age of the rocks in which they occurred.

In 1878 Mr. Clarence King² reported the occurrence of Permian strata in the Wasatch and Uinta mountains, and represented the Permian on the maps accompanying the Fortieth Parallel Report.

In 1880 and later, in 1885, Capt. (now Major) C. E. Dutton³ described rocks with Permian affinities in the Plateau region, and at Fort Wingate, New Mexico. He was able to trace these strata, which he describes as Permo-Carboniferous, over the greater part of the Plateau region, to identify them with the Shinarump conglomerate, which had been previously described by Powell, and to establish a direct stratigraphic correlation with the beds which King had called Permian in Utah and Wyoming and northwestern Colorado. At this time Dutton called attention to the probability that the Permo-Carboniferous would eventually be found in the southwestern part of Colorado.

In 1880 Mr. C. D. Walcott,⁴ in a paper entitled *The Permian and Other Paleozoic Groups of the Kanab Valley, Arizona*, described as of Permian age a series of gypsiferous and arenaceous shales and marls, with occasional limestone bands. The group was divided by both stratigraphic and paleontological evidence into an Upper Permian and Lower Permian series. The upper series was considered, from its fossils, to be of true Permian age; while the lower series has a fauna containing certain Carboniferous types mixed with the Permian. This

¹ U. S. Geol. Surv. W. One hundredth Mer., Vol. III, Geology, 1875, p. 177.

² U. S. Geol. Expl. Fortieth Par., Vol. I, 1878, p. 343.

³ Bull. Philos. Soc. Washington, Vol. III, 1879, p. 67, Sixth Ann. Rept. U. S. Geol. Survey, 1885, p. 134.

⁴ Am. Jour. Sci., 3d series, Vol. XX, pp. 221-225.

lower series was indicated as equivalent to the beds which Gilbert called Permo-Carboniferous, and attention was again called to the equivalence of this general Permian section with that described by King in the region to the north. It was further suggested that the Permian, as found in the Kanab section, must extend toward the west, east, and southeast in Arizona and New Mexico.

Permian fossils, consisting for the most part of plant remains, have been reported from various parts of Colorado by members of the Hayden Geological Survey,¹ but the collections and the systematic study of the formations were not sufficiently complete to establish the presence of rocks of this age in such development that they could be separated from the Trias above or from the Carboniferous below. It thus remained for the present investigation to reveal the occurrence of strata with Permian affinities as a definitely separable formation within the limits of Colorado.

The fossils obtained from the Rico formation have been studied by G. H. Girty, who reports that the fauna is a mixed one, containing fossils of both Permian and Carboniferous affinities. For this reason he considers the Rico beds as transitional, and is inclined to retain the term Permo-Carboniferous to apply to them. He states, however, that if it were necessary to assign the fauna to either the Coal Measures or the Permian, the line between the two should be drawn at the base of the Rico formation rather than at its top.

In attempting to establish the position of the Rico beds Mr. Girty has especially considered the section occurring in eastern Kansas which has been described by Prof. C. S. Prosser, and finds a similarity in the fossils of the Rico formation and the lower part of Prosser's Permian, the Neosho and Chase formations, which correspond to the Permo-Carboniferous of earlier writers.

The lower Permian of the Kanab region, described by Walcott, is also transitional between the Coal Measures and the typical Permian, as shown by a similar mixture of fossils, so that there is good basis for correlating the Rico formation both with the Lower Permian or Permo-Carboniferous of the Mississippi and with that of the Plateau region.

The occurrence of typical Permian both in Kansas and in Arizona suggests a query as to its presence or absence in the San Juan region of Colorado. Upon this point it can only be said that the lower strata included in the Dolores formation rest with apparent conformity upon the Rico beds, suggesting that the true Permian should be represented; but these lower beds of the Dolores have not yielded fossils in all this region. Possibly if the Rico formation had been recognized at the time the Dolores formation was defined it would have seemed as appropriate to have placed the lower, unfossiliferous portion in the Permian

¹See Report on the geology of the Grand River division, by A. C. Peale: U. S. Geol. and Geog. Surv. Terr. for 1875, p. 74.

as to have included it in the Juratrias; but the latter procedure was in accord with the general lithological similarity throughout the Red beds, and this correlation can not be assailed by evidence.

The following forms have been identified from the Rico formation:

Fossils from the Rico formation.

<i>Fusulina cylindrica</i> .*	<i>Schizodus cuneatus</i> ?
<i>Chonetes mesolobus</i> .*	<i>Schizodus meekanus</i> .
<i>Chonetes glaber</i> .	<i>Pleurophorus subcostatus</i> .
<i>Productus prattenianus</i> .*	<i>Allorisma terminale</i> .*
<i>Productus nebraskensis</i> .*	<i>Sedgwickia topekensis</i> ?
<i>Seminula subtilita</i> .*	<i>Edmondia gibbosa</i> .
<i>Monopteria polita</i> .	<i>Astartella</i> ? <i>gurleyi</i> .
<i>Monopteria polita</i> var. <i>ricoensis</i> .	<i>Bulimorpha chrysalis</i> .
<i>Monopteria gibbosa</i> ?	<i>Naticopsis altonensis</i> .
<i>Posidoniella pertenuis</i> .	<i>Naticopsis monilifera</i> .*
<i>Posidoniella recurva</i> ?	<i>Strophostylus remex</i> .
<i>Aviculopecten occidentalis</i> .*	<i>Euconispira</i> cf. <i>turbiniformis</i> .
<i>Pseudomonotis hawni</i> .*	<i>Euconispira taggarti</i> ?
<i>Pseudomonotis hawni</i> var. <i>equistriata</i> .	<i>Murchisonia</i> ?? <i>marcouiana</i> .
<i>Pseudomonotis tenuistriata</i> .	<i>Loxonema</i> ? <i>peoriense</i> .
<i>Myalina perattenuata</i> ?	<i>Loxonema plicatum</i> .
<i>Myalina subquadrata</i> .*	<i>Bellerophon giganteus</i> ?
<i>Myalina hindana</i> .	<i>Bellerophon crassus</i> .*
<i>Aviculopinna peracuta</i> .*	<i>Pattelostom bellum</i> .*
<i>Schizodus pandatus</i> ?	<i>Euphemus carbonarius</i> .*

*Species marked by an asterisk occur also in the Hermosa formation.

JURATRIAS.

Introductory.—All the Juratrias formations of the San Juan region are represented in the Rico Mountains. Beginning at the base, they are the Dolores Red beds, 1,600 feet in thickness; the La Plata sandstone, 250 feet or more, and the McElmo shales and sandstones, exposed to a thickness of 300 feet within the area represented on the map, but having a total thickness of nearly 900 feet in the region adjacent. The reasons for the subdivision which is here adopted are fully given in the Telluride folio, and there certain moot questions as to age and correlation have been fully discussed, so that these points need not be considered in this place.

The materials of the lowest formation are such as might be derived from the rapid weathering of a continent made up largely of granitic rocks, with areas of schist and quartzite, and are doubtless evidence of the former existence of such a land area adjacent to the San Juan region at the time of their deposition. The materials are similar and the conditions under which they were laid down were like those of the underlying uppermost formation of the Carboniferous, but comparison with the materials of the La Plata indicates a complete change of conditions, from such as favored rapid deposition of hetero-

geneous rock débris to those favoring complete sizing and sorting of land-derived materials. Probably the La Plata will be found elsewhere to be unconformable with the Dolores, but in the Rico region there is no evidence of any break in deposition.

The McElmo formation is different from the La Plata in the large amount of green clay shale which enters into its composition. Its sandstones have the same character as those of the lower formation, and no important or far-reaching change of conditions need be postulated to account for its differences. Though described as Juratrias, it seems to be transitional between that system and the Dakota sandstone, of Upper Cretaceous age.

These three formations are easily distinguished in the field, and on the map the distribution of each is represented by a distinct pattern of the Juratrias color.

DOLORES FORMATION.

Definition.—The Dolores formation, as described in the Telluride folio, has been made to comprise the Triassic strata of southwestern Colorado and adjacent territory. The name is derived from the Dolores River because of the typical exposures along its course in the Rico quadrangle and its known occurrence throughout the greater length of the Dolores Valley. Along the upper course of this river and in the Animas region the formation has a thickness of approximately 2,000 feet, but to the west its thickness diminishes until it is scarcely half this amount in the vicinity of the La Sal Mountains. The formation is composed of generally reddish sandstones, grits, conglomerates and shales, and is calcareous throughout. It is delimited below by the Rico formation and above by the La Plata sandstone, of assumed Jurassic age. Vertebrate, invertebrate, and plant remains have been found in the upper part of the formation, and upon their evidence the Triassic age of that part of the series is considered as established. Whether or not the lower part is correctly included in the Dolores remains to be determined by future discoveries.

General description and subdivision.—As pointed out in the Telluride folio, where it was first described, the Dolores formation has the general characteristics of the widely known Red beds of the Rocky Mountain region. The strata are mostly of a bright vermilion color, but include a gray or green series in the upper half and occasional light-colored sandstones and conglomerates in the lower part. The rocks comprise sandstones, grits, and conglomerates in alternation with sandy shales, with which earthy limestones are frequently associated. Throughout the entire thickness the strata are characterized by a calcareous cement, in which respect they resemble the rocks of the Hermosa and Rico formations, and are in distinct contrast with the friable or quartzitic sandstones of the La Plata and higher formations.

Individual beds of coarse sandstone or conglomerate of uniform texture are seldom more than 25 or 30 feet in thickness, although fine-grained and thin-bedded sandstones with only slight textural variations may exceed 100 feet. Nearly all beds vary greatly in constitution and thickness, so that detailed sections made at points not widely separated can seldom be closely correlated.

The materials of which the Dolores strata are composed were derived from granites, schists, and quartzites, which formed a continental area in or near the present area of the San Juan during Triassic time. The coarse grits are made up of fresh granitic sand, and the conglomerates contain pebbles of schist and quartzite, with occasional fragments of granite or fine-grained igneous rocks.

In the Rico region the Dolores may be divided into two parts; a lower coarser-grained and unfossiliferous series containing many arkose and conglomeratic sandstones, and an upper finer-grained series comprising at its base gray and green shales with light-colored sandstones and fossiliferous limestone conglomerates and above these vermilion-colored calcareous shales and fine-grained sandstones to the bottom of the La Plata.

The total thickness of the formation at Rico is approximately 1,600 feet, of which 1,100 or more belongs to the lower portion and the rest to the upper division.

Lower, unfossiliferous division.—No continuous exposure of the lower portion of the Dolores is available for study in the Rico region, but from various partial sections its general features are known. The character of the strata as seen in the lowest beds as exposed in Scotch Creek south of the area of our special map, in the central portion as studied in the southeast corner, and in the upper part as exposed within the drainage of Hermosa Creek to the east of the area mapped, is shown in the following sections:

Section (from top downward) of lower portion of Dolores formation in Scotch Creek.

[Base of section only a few feet above the highest fossiliferous stratum of the Rico formation.]

	Feet.
31. Sandstone, micaceous, red or green, carrying a thin layer of coarse conglomerate near the top.....	10
30. Arkose sandstone, cross bedded, white.....	20
29. Sandstone, micaceous, red and green.....	6
28. Arkose sandstone, coarse grained, white.....	7
27. Sandstone, compact, micaceous, salmon color to red.....	10
26. Calcareous shales, green and brown.....	5
25. Sandstone, micaceous and compact, containing layers of gnarly limestone from 2 to 12 inches thick.....	18
24. Calcareous sandstone, generally red but mottled; contains thin layers of gnarly limestone.....	15
23. Arkose sandstone, cross bedded and conglomeratic in part; this layer is purple at the base and this color alternates with greenish-yellow and red bands; in the upper part a white and cream color prevails.....	30
22. Sandstone, rather flaggy, containing a layer of gnarly limestone at the base.....	18

	Feet.
21. Calcareous sandstone, shaly in the lower part and containing gnarly limestone near the top; bright red	10
20. Sandstone, micaceous, massive, becoming flaggy at the top, where it contains limestone nodules; red	5
19. Calcareous sandstone, containing small limestone nodules near the top; red	5
18. Calcareous sandstone and red arkose, containing limestone pebbles; purple and white in the upper part, red below	12
17. Covered	12
16. Arkose sandstone, variegated; red, white, and purple exposed	6
15. Sandstone, micaceous, flaggy	5
14. Arkose sandstone, flaggy, becoming finer grained and micaceous in the upper part; pink with narrow white bands	15
13. Arkose sandstone, somewhat conglomeratic in the upper part, and with thin shaly bands near the center and at the top; white and pink, irregular bands	35
12. Sandstone, micaceous, flaggy, very thin-bedded at top; red	10
11. Calcareous sandstone; a few thin layers of nodular limestone; red	7
10. Sandstone, micaceous, flaggy; red	6
(a Porphyry, 8 feet.)	
9. Sandstone, micaceous, flaggy, becoming more compact in the upper part ..	15
8. Arkose sandstone, white, banded with red	7
7. Calcareous sandstone, rather poorly exposed in the upper part, but flaggy and somewhat shaly, becoming more shaly in the lower part, and containing nodules of limestone; red	35
6. Arkose sandstone, red above, white below	6
5. Shale, probably calcareous, contains nodules of limestone; red	5
4. Sandstone, micaceous; dark purplish red	5
3. Calcareous sandstone, irregularly nodular and flaggy; contains gray nodules of limestone but no well-defined limestone; red	25
2. Arkose sandstone, micaceous, thin conglomeratic, cross bedded; near the base there is a thin black shale which is quite variable; white, with bluish and green zones	15
1. Calcareous sandstone, with a gnarly gray limestone at the top; red	10
Total	390

The partial sections exhibited at many places in the eastern half of the Rico Mountains, as in Whitecap Mountain and the similar porphyry-capped summit just east of it, show that the section above given represents in a general way the constitution of the entire unfossiliferous Dolores, for near the summit of Blackhawk Peak the lowest limestone conglomerates appear.

Section from the base of the La Plata sandstone downward, including the upper member of the Dolores and the uppermost 300 feet of the lower member.

[The section was made on the south slope of the hill seen in Pl. I, where the La Plata sandstone appears as a white band, dipping easterly.]

	Feet.
37. From the base of the La Plata sandstone an alternation of calcareous sandstones and shales	200
36. Coarse limestone conglomerate, grading upward into a red calcareous sandstone like that which is called "typical Red beds." Many of the pebbles in these conglomerates have the appearance of being of concretionary origin	5

	Feet.
35. Finely laminated clay shales of a gray color, with some sandy layers.....	16
34. Sandy shale, very thin bedded; red	25
33. Sandstone, massive and fine grained; dull red	25
32. Structureless layers; dull red	15
31. Limestone conglomerate.....	3
30. Gray shale and fine-grained sandstone, alternating, passing downward into the next	25
29. Shales of a gray-green color.....	11
28. Fine-grained dull-red sandstone, massive as a whole; rather flaggy in detail	30
27. Limestone conglomerate	10
26. Gray shales, containing four thin layers of limestone conglomerate.....	20
25. Limestone conglomerate.....	4
24. Gray shales	10
23. Gray, sandy shales, containing two or three thin bands of limestone conglomerate; the upper one full of tooth fragments.....	8
22. Limestone conglomerate, rather flaggy	3
21. Sandstone, gray and green.....	1
20. Limestone conglomerate	1
19. Shale and very fine-grained sandstones of a gray-green color, containing a 4-inch layer of limestone conglomerate at the base	6
18. Red, structureless shale	3
17. Peculiar clay shale of a red color, containing plums of red and white limestone sprinkled throughout; these nodules are from $\frac{1}{2}$ inch to 3 inches in diameter	10
16. Not well exposed, but probably typical Red beds.....	15
15. Prominent bed of sandstones, containing blue concretions of limestone in the upper part; these concretions show a concentric structure; orange color.....	11
14. Typical Red beds, rather shaly	10
13. Coarse arkose sandstone, conglomeratic in the lower part.....	20
12. Typical Red beds; not particularly massive	30
11. Prominent massive beds of the typical Red-bed character; orange color ..	30
10. Typical Red beds and even-grained arkose sandstones	35
9. Typical Red beds	6
8. Conglomerate, containing pebbles up to 6 inches in diameter	10
7. Typical Red beds.....	17
6. Arkose sandstone, rather fine grained, massive; dark red.....	35
5. Typical Red beds	18
4. Arkose sandstone, cross bedded, white in the upper part, red below.....	12
3. Typical Red beds.....	2
2. Arkose sandstone, cross bedded, conglomeratic in the lower part.....	14
1. Typical Red beds, exposed, about.....	35
(At this place a fault crosses and the continuity of the section is broken.)	
Total	731

From these sections it may be seen that while there are many beds of coarse arkose and conglomerate in the lower division of the Dolores, a large portion of the strata are of the fine-grained calcareous sandstone or sandy shale which is noted as "typical Red beds." In the last section given these calcareous marls form fully one-half the thickness exposed below the Saurian series, including numbers 1 to 16.

The color of the lower Dolores is variable. The arkose sandstones and conglomerates are either uniform dull red, red streaked with white, or of a pink shade; while the calcareous marls are always bright vermilion, and the nodular limestone bands or lenses are usually of gray shade.

No fossils are known to occur in these lower strata, and for this reason, and in the light of the occurrence of Permo-Carboniferous fossils in the Rico formation, it is thought possible that the coarse-grained division may ultimately be found to belong to the true Permian, and thus to represent strata which are known in the Plateau region¹ to the west and in the Plains region to the east of the Rocky Mountains. This is a matter to be settled by future work, and for the present it seems best to place the whole series in the Mesozoic.

Upper, fossiliferous division.—The upper division of the Dolores formation shows a thickness of 431 feet in the section given on p. 70. At Rico it consists of two distinct series. At the bottom there are 230 feet of alternating sandstones, sandy and clay shales, and limestone conglomerates. The sandstones are gray or yellow flags, apparently not so calcareous as the usual sandstones of the formation, since they are often rather friable. The shales are soft and argillaceous as a rule, though sometimes sandy; their color is either greenish gray or a dull red. Carbonaceous matter, often representing plant stems, is abundant in the shaly sandstones of many localities, but no determinable specimens have as yet been found.

The coarser limestone conglomerates are made up of rather angular pebbles of dense bluish limestone, some of which are 4 or 5 inches in diameter, set in a matrix of limestone which is usually earthy and often shows an admixture of quartz grains. In some cases, where the pebbles have a rounded form and show septarian cracks, it seems likely that they have originated practically in situ, but in the majority of cases it seems that they have been derived from the breaking up of preexisting limestone strata. If they were derived from the limestones of the Hermosa formation it would seem curious that no Carboniferous fossil fragments have ever been noted in the conglomerates; and their absence allows room for doubting that the conglomerates are really made up of broken fragments derived by wave action from outcrops of an older formation along the shore adjacent to which they were deposited. If the materials were so derived it is further anomalous that there is so small a proportion of siliceous sand mixed with the limestone pebbles, and that limestone strata should have been alternately exposed and hidden for the formation of the successive conglomerate layers and the strata of entirely different character with which they are interbedded. The finer-grained conglomerates are ordinarily

¹The Permian and other Paleozoic groups of the Kanab Valley, Arizona, by C. D. Walcott; Am. Jour. Sci., 3d series, Vol. XX, 1880, pp. 221-225.

but a few inches in thickness in this region. They are almost pisolitic in appearance but no concentric structure has been noted. In the light of these difficulties it may seem possible that the conglomerates were derived from the breaking up of limestones in process of synchronous formation. This must, however, be regarded merely as a suggestion, since the conglomerate has not yet received the study which must precede any theory to account for its formation. For the limestone conglomerates the term "Saurian" conglomerates has been used in the field, and this was found a convenient designation in the description of them in the *Telluride folio*. The origin of this name is found in the fossil bones and teeth of dinosaurs, associated with those of crocodiles, which occur generally in the conglomerates, and which, while usually fragmentary in this region, are elsewhere much better preserved. They are considered by paleontologists characteristic of the Trias.

Above the Saurian conglomerate series the remainder of the upper division of the Dolores in the Rico region is made up of typical Red bed marls and sandy shales in alternation, without coarse sandstones. The uppermost strata are of a bright vermilion color.

In the section given on page 70 the upper division of the Dolores is represented by numbers 17 to 37, all but the last belonging to the Saurian series.

The upper part of the Dolores has been referred to as fossiliferous, and so it is in almost every locality where the Saurian series is found to outcrop. Fragments of Saurian bones and teeth are by far the remains of most frequent occurrence, and though these have proved sufficient for identification in some few cases, they are not as a rule determinative. A single specimen of a gasteropod, which in the opinion of T. W. Stanton is a species of *Viviparis*, was discovered in the Saurian series near Rico. A single species of fossil plant is known from the Dolores formation, which was collected from a coarse conglomerate outcropping upon the river bank north of Rico. This was determined as *Pachyphyllum münsteri* by David White. A complete discussion of the age relations of the Dolores formation has been given in the *Telluride folio*, to which the reader is referred.

Distribution and occurrence.—The Dolores formation forms the rock surface over perhaps half the extent of the area under discussion, occurring around the central uplift outside of the Rico beds, and extending to the limits of the area mapped, except in the northwest and southwest corners, where it is covered by the La Plata sandstone. The characters of the lower coarse portion may be best studied at the localities of the recorded sections, and in general in the eastern part of the region. Good exposures may be found on the western slopes of Whitecap Mountain and of Dolores Mountain, and elsewhere near the headwaters of Deadwood and Allyn gulches. In the lower part of Silver Creek, while the strata are well exposed above the cliffs

of the Rico beds, both formations have been decolorized by the slight metamorphism which they have undergone. In Telescope Mountain and in the ridge north from it the coarse series is well exhibited as to its general characteristics, and again in the upper part of Sandstone Mountain and the slopes north of Horse Gulch. As a rule the coarse series is not well shown in the western half of the mountains, and except in the cliffs south of Burnett Creek is exposed only locally and to no great thickness. In the cliffs mentioned several hundred feet of these beds are exposed above the Rico formation, but no peculiarities are presented.

In the northeastern corner of the mapped area the Upper Dolores is found upon the ridge between McJunkin and Barlow creeks, where the limestone conglomerates of the Saurian series are coarser than usual and contain, in the case of the lowest beds, some fragments of granite and gneiss. In this region the conglomerates carry many worn fragments of bone.

On the west side of the river the Saurian beds outcrop in the ridge between Elliott Peak and Sandstone Mountain, above the saddle, at 11,000 feet, and may be found also on the opposite side of Papoose Basin at 11,750 feet, and again upon the main divide west of Sockrider Peak. From the structure indicated on the map, considered in relation to these outcrops, it is thus seen that all of the Dolores formation exposed in the southwestern corner of the area mapped belongs to the upper division.

Southward from Johnny Bull Hill, where the base of the La Plata is found dipping toward the north, no horizons are to be recognized until the Saurian conglomerates appear through the reversed structure on the southern side of the dome at the head of Burnett Creek. In the upper part of the southernmost drain of Stoner Creek the Saurian series is well exposed and may be studied to good advantage; also portions of the series may be examined in the rounded knob upon the main ridge to the east, the summit of which is 11,900 feet. From this place the base of the upper division falls rapidly into the drainage of Wildcat Creek and soon passes beyond the limits of the area mapped.

The only place where rocks belonging to the upper division are found in the high eastern mountains is in Blackhawk Peak, where 150 or 200 feet of the flaggy sandstones of the Saurian series and several of the limestone conglomerates are exposed. Elsewhere the higher portions of the formation have been completely eroded.

LA PLATA FORMATION.

Definition.—The La Plata formation has received its name from the La Plata Mountains, where it is characteristically exposed. In the Rico quadrangle, as has been pointed out for the Telluride region, it

is proper to call the formation the La Plata sandstone. It includes two massive sandstone strata, with a series of shaly sandstones between them, lying above the Dolores Red beds and below the green marly shales of the McElmo formation.

Description.—The La Plata sandstone is made up of three members. Its thickness varies from 100 to 500 feet in the San Juan region, while toward the northwest, in the Canyon and Plateau regions, it expands to two or three times the maximum figure for the San Juan. In the Rico region its minimum is not less than 250 feet, while its greatest thickness is nearly 500 feet.

The basal member of the La Plata is ordinarily about 90 feet thick in the Rico region, though on the west fork of the Dolores it diminishes to 10 feet at one place. It is a fine-grained saccharoidal sandstone, very massive except for a few feet at the top and bottom, and cross-bedded on a large scale. The direction of the cross bedding is extremely variable and seems to be entirely lawless, being very different in the parts of the sandstone lying above one another, and changing from place to place horizontally. The upper limit of this member is frequently revealed by a marked bench or shoulder along the slopes upon which it outcrops. The next member is in general quite as variable in thickness and is less homogeneous than the two sandstones between which it lies; within the Rico area it varies from 75 to 260 feet. In the Telluride and Animas regions its base is characterized by a dark bituminous limestone, but this is not present in the Rico occurrences, though its horizon is marked by a calcareous sandstone, probably representing a transition to limestone, in the first appearance of the formation east of Rico. Aside from this stratum of local occurrence the middle member is made up of friable sandstones and sandy shales of subdued red tones, with intercalated layers of white sandstones, also friable. The red portions of the series sometimes resemble the Dolores formation, but can seldom be confused with its strata. A thin band of white sandstone is frequently observable which contains little rosettes of carnelian; a feature which, where it occurs, may be safely taken as characteristic of this middle member. In the Rico region the upper sandstone is uniformly about 75 feet thick, being thus thinner than the usual development of the lower member, which it resembles both in its materials and in its texture, and also in the cross bedding which it exhibits.

The materials of the La Plata formation were doubtless derived from the same continent, and therefore from the same rocks, as those of the sediments which preceded, but they were certainly subjected to a different and more severe treatment upon the beaches of the sea. This conclusion is suggested by their being very perfectly assorted and composed almost entirely of quartz, in which point they are in marked contrast with the undecomposed arkose, which varies greatly

in size of grain and which is so abundant in the Carboniferous and Triassic formations. It seems probable that the Jurassic period was ushered in by a temporary uplift of the San Juan and adjacent land areas preceding later sinking which was concomitant with deposition; but whatever the physical change may have been which brought about these differences of sedimentation, conditions similar to those of Triassic time have not since occurred in the San Juan region.

The La Plata formation was studied in the cliff exposure of the hill seen in Pl. I, to the east of the eastern line of this special map, within the Engineer Mountain quadrangle. The section is continuous with the one of the Dolores formation taken at the same place (pp. 69-70). It illustrates the threefold nature of the formation, two massive sandstones being separated by a series of sandy shales and thin beds of sandstone.

Section (from top downward) of the La Plata formation.

	Feet.
6. Sandstone, rusty brown or gray, in banks separated by thin layers of crumbling, sandy shale; a few of the lower sandstone layers are calcareous.	73
5. Red sandy shale.....	8
4. White saccharoidal sandstone	4
3. Sandy shales, crumbling very readily, containing a few thin layers of sandstone; these are the most abundant in the upper part; about 15 feet from the base there is reddish chert in considerable abundance; at 40 feet from the base there is a very impure, dull red, earthy and sandy limestone; the color of the whole series is reddish.....	60
2. Dark, calcareous sandstone, containing considerable calcite near the middle, 3 to 4 feet.....	4
1. Massive sandstone of the usual La Plata character.....	104
Total.....	253

Distribution and occurrence.—The La Plata sandstone does not now occupy extensive areas in the Rico Mountains, being exposed, as a rule, in the upper part of the slopes which border the courses of the main streams, where its massive layers are indicated by steeper slopes than those in which the Dolores and McElmo formations outcrop. Those outcrops which are nearest the center of the dome are at approximately the same elevation, and the relations of this formation serve very well to show the quaquaversal structure of the Rico Mountains. This feature is not completely shown on the special map, since its extent to the east and north is not sufficient to comprise the adjacent occurrences. Within the area of the special map the La Plata is confined to the southwest and northwest corners. In the former the La Plata occupies only a small area, but in the latter it is more widely distributed, occurring in Johnny Bull Mountain and Elliott Mountain and in the drainage which lies between these prominent points.

The La Plata formation, because of its massiveness, is always promi-

nent in its outcrop, and especially, as illustrated at Rico, it forms knobs where it cuts across the ridges.

Correlation.—The La Plata sandstone represents the lower portion of the Gunnison formation, as described in the Anthracite-Crested Butte folio, though exact correlation is not possible, since there appears to be no sandstone in the Elk Mountains to correspond with the upper member of the formation as known in the San Juan. It is probable, however, that the limestone containing fresh-water shells in the Elk Mountains represents the same horizon as the limestone which occurs in the San Juan, but the latter has thus far yielded no distinctive fossils, though some indistinct fish scales and vertebrae were found in the northern part of the Engineer Mountain quadrangle. In the Plateau region of Utah Dutton recognized a massive white sandstone overlain by bright-colored shales and intercalated sandstones, which is distributed over a wide area, and this he called the Jurassic white sandstone. There is little doubt that it is to be correlated with that portion of the Jurassic which has been called the La Plata formation in the San Juan region.

McELMO FORMATION.

Definition.—The name "McElmo" was proposed in the Telluride folio for the series of shales and sandstones which lies between the La Plata and the Dakota formations. This formation, like most of the others occurring in the southwestern part of Colorado, is quite variable in thickness, its minimum being about 400 feet and its maximum about 1,000 feet.

Description and occurrence.—In the Rico region the McElmo has a fairly uniform thickness of somewhat less than 500 feet, and with this decrease in thickness it is found to be composed more largely of shales than in the Telluride quadrangle, where its thickness is nearly twice as great, and where sandstone forms an important element of the series. These variations in thickness do not interfere, however, with the certain and easy recognition of the formation by reason of its characteristic lithological features. It consists of alternating shale and sandstone in variable proportions; the shales are usually apple-green, but sometimes deep Indian red, with occasional variegated bands of red and green. They are fine grained or sandy and occur in homogeneous bands, usually several feet in thickness, and within these bands there is little or no lamination. The finer-grained strata have a porcelainous texture and a conchoidal fracture, causing the shale to break up into small more or less cubical fragments. The sandstones are usually even grained and friable, those in the lower portion resembling the sandstones of the La Plata, while at least one of the upper beds is like the Dakota; both are white or yellowish and are found to grade horizontally into sandy shale, and thence into clay shale.

Perhaps the most constant element of the section is the sandstone or conglomerate which occurs in the upper part. This bed is indistinguishable from the lowest conglomerate of the Dakota, and is characterized by small subangular pebbles of some white material, which is probably impure chert.

Within the Rico quadrangle, the formation is seldom well exposed, though its thickness may be made out in nearly every place, and it is found to vary but little. It forms a gentle slope between the steeper slopes of the Dakota and La Plata formations. The only section which was measured in the Rico quadrangle was found upon the north side of the West Dolores, above Love's ranch. At this place there was, immediately below the sandstones of the Dakota, 35 feet of fine-grained green shale with a few bands of sandstone; next a conglomerate carrying white impure chert about 15 feet in thickness, and then an alternation of dull-red and green shales with thin sandstones for a thickness of 275 feet, the whole thickness of the formation being in the neighborhood of 425 feet. The entire thickness of the McElmo does not occur within the Rico special area. As indicated on the map, there are five small patches of the formation, distinct from one another, lying above the La Plata sandstone. These are tongues which extend up along the ridges from the more extensive areas adjacent.

Correlation.—The McElmo formation represents the upper part of the Gunnison formation, as it is shown in the Elk Mountains, and is therefore, in part at least, equivalent to the Morrison formation occurring upon the east side of the Front Range. It has a very considerable but unknown extent in the portions of Utah, Arizona, and New Mexico adjacent to this part of Colorado.

No fossils are known in the San Juan region, but their established relation with the Morrison beds must at present be sufficient evidence of their Jurassic age.

CRETACEOUS.

Although the Mesozoic formations above the McElmo are not present in the area represented by the special map of the Rico Mountains, the Dakota sandstone and the Mancos shales occur in the immediate vicinity, and the latter is found to pass upward into the coal-bearing formations in the Mesa Verde region to the south and in the Lone Mesa to the west, and the general geological history of the region indicates that all of the Cretaceous formations of the region were laid down over the present site of Rico. Judging from the nearest known outcrops of these formations, their aggregate thickness was approximately 6,000 feet, as compared with 11,500 feet of Mesozoic and Paleozoic strata below them.

The series of conformable Cretaceous formations was terminated by uplift,¹ after which erosion ensued in the region which is now occupied by the San Juan Mountains, as is evidenced by the unconformable relations of the ensuing formations in the Telluride and Silverton quadrangles and in the adjacent regions to the north and east.

¹ Orographic movements in the Rocky Mountains, by S. F. Emmons: Bull. Geol. Soc. Am., Vol. 1, 1890, p. 280 et seq.

CHAPTER III.

THE IGNEOUS ROCKS AND THEIR OCCURRENCE.

By WHITMAN CROSS.

PETROGRAPHY.

As has been pointed out in the outline of the geology, the igneous rocks of the Rico Mountains belong to a few kinds, most of which have been previously observed in association. In the systematic descriptions to be given they will be considered under the following divisions: Monzonite; porphyries associated with the monzonite; hornblendic monzonite-porphyry; porphyry of Calico Peak and vicinity; basic dike rocks.

MONZONITE.

General description.—The mass of the large stock west of Rico is a granular rock containing orthoclase and plagioclase in about equal amounts, carrying a little quartz in most places, and with a variable development of augite, hornblende, and biotite. The feldspathic constituents strongly predominate over the ferromagnesian silicates. The rock thus belongs in the group intermediate between the syenites and diorites to which Brögger has recently given the name monzonite, from the type locality of Monzoni, near Predazzo, in Tyrol.¹

The rock is, as a rule, of medium grain, the variation in this respect ranging from rather coarse to fine grain, but not to a texture that is strictly aphanitic. With a hand lens nearly all the mineral particles can sometimes be recognized in the coarser specimens, including apatite, titanite, and magnetite. The structure is ordinarily

¹ W. C. Brögger, *Die Eruptivgesteine des Kristianiagebietes*. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtirol, 1895, pp. 6-64. The proposition of Professor Brögger to establish a group of rocks between syenite and diorite and coordinate in importance with them has been so welcome to the petrographers of the United States Geological Survey that the use of the terms monzonite and quartz-monzonite in the folios of the Survey has been authorized by the Director, in accordance with the recommendation of a special committee. The further proposition made by Brögger to subdivide the quartz-monzonites, which stand intermediate between the granites and the quartz-diorites, into banatite and adamellite, according to the amount of quartz present, has not yet been specially considered.

typically granular, with local tendency to a poikilitic development in which orthoclase is the host and includes all other constituents. This structure is rarely very prominent megascopically, but almost invariably appears in some degree under the microscope.

In mineralogical constitution the feldspars always exceed the ferromagnesian minerals and the rocks are therefore grayish in color. The darker modifications are also the finer grained and often owe their shade to the finer particles of the dark silicates. The two feldspars are distinguishable in some places through the pinkish color of the orthoclase, but this is entirely lacking in many areas and the rock has then the appearance of a diorite, the term which would have been applied to these masses a few years ago.

The lime-soda feldspar, plagioclase, has the usual development in such rocks, being in rude crystals about which the orthoclase has oriented itself to some extent, as seen in some of the thin sections examined. A combination of the albitic and Carlsbad twinning laws is not rare, and applying the Michel Lévy method to such crystals it has been found that labradorite of Ab_1An_1 is the most common plagioclase. There is strong zonal structure in many crystals, and it is possible that andesine is also present in individual crystals in some places.

The unstriated feldspar is undoubtedly orthoclase. It occurs in anhedral grains, often filled with dusty inclusions giving it the pink color above mentioned. Without tendency to form regular crystals it almost invariably surrounds grains of other constituents and often presents the poikilitic structure in fine development. No micropertitic intergrowth was observed.

Quartz is present only as a very subordinate constituent in small angular grains intimately associated with the orthoclase. In some portions of the mass it constitutes several per cent of the rock, which then becomes quartz-monzonite, or banatite, if the term proposed by Brögger for such types be accepted. As a whole, the amount of quartz may be considered as accessory and not requiring recognition in the name.

The granular rocks of the stock are characterized in contrast to the monzonite-porphry of the prevalent sheets by the appearance of augite and biotite as dark constituents. In some of the most distinctly granular forms of certain knolls on Darling Ridge the only dark silicates present are augite and biotite, but in other places hornblende appears in abundance, often intergrown with augite. It is developed to the exclusion of augite in rare instances. This hornblende, though dark green in color, is more vivid in hue than that of the porphyry sheets and has a somewhat weaker pleochroism.

Apatite and titanite are prominent accessory constituents of these monzonites. The latter is distinctly visible in the hand specimen in

honey-yellow crystals of the common development. Apatite occurs in a few large crystals, and not infrequently the naked eye may detect the glassy hexagonal prisms with pyramid. Magnetite is quantitatively of less importance than usual, and its development is like that of apatite, viz. in a few large grains easily detected with the unaided eye.

Variations of the monzonite.—The variations in texture and in composition above noted bear no evident causal relation to the boundaries of the stock as now exposed. Now hornblende, now augite predominates all through the mass. The finer-grained rocks are not necessarily near the borders, nor are the facies richest in dark silicates so related. No abrupt boundaries between modifications were seen, such as might indicate that certain forms were later intrusions. It is true that the exposures are not sufficiently continuous to warrant the assertion that there are no dikes cutting the main mass. Indeed, it seems probable that there are dikes of the porphyry, to be described in the next section, but none of granular rock was observed. It appears, therefore, that the magma filling the stock conduit was nearly homogeneous and suffered no considerable differentiation in situ.

Relations to other occurrences.—No chemical analyses of the Rico monzonite have been made, as it seemed unnecessary in view of those already existing of nearly related rocks collected by the writer from other stocks of southwestern Colorado. In the table below are given analyses of four monzonites of this region and of two foreign rocks from classic localities.

Analyses of monzonite and quartz-monzonite.

Constituent.	I.	II.	III.	IV.	V.	VI.
SiO ₂	65.70	65.84	63.91	57.42	57.66	55.53
Al ₂ O ₃	15.31	15.23	17.07	18.48	17.23	16.80
Fe ₂ O ₃	2.54	3.93	4.39	3.74	7.28	4.06
FeO.....	1.62	.....	1.51	2.10	.....	3.35
MgO.....	1.62	2.21	.81	1.71	2.20	3.00
CaO.....	2.56	4.74	4.47	6.84	5.32	6.96
Na ₂ O.....	3.62	2.96	3.48	4.52	3.41	4.31
K ₂ O.....	4.62	3.02	3.74	3.71	4.61	3.57
H ₂ O below 110°.....	.17	.....	.....	.08	.....	.55
H ₂ O above 110°.....	.42	.98	.33	.28	.70	.09
CO ₂.....	.....	.....	.....	.....	.....	.09
TiO ₂.....	.72	.....	.....	.86	.....	.95
P ₂ O ₅.....	.33	.....	.21	.36	.....	.47
SO ₃.....	.12	.....	.....	.....	.....	.....
Cl.....	.03	.....	.....	.03	.....	.....
MnO.....	Trace.	.....	.....	.09	.....	.16
BaO.....	.12	.....	.....	.15	.....	.13
SrO.....	.03	.....	.....	.08	.....	.11
Li ₂ O.....	Trace.	.....	.....	.....	.....	Trace.
FeS ₂.....	.....	.....	.....	.....	.....	.04
Total.....	99.53	.....	99.92	100.45	.....	100.17

I. Quartz-monzonite (banatite). Northeast of San Miguel Peak, Telluride quadrangle, Colorado, Telluride folio, No. 57, Geol. Atlas of U. S., 1899, p. 6. Analyst, H. N. Stokes.

II. Banatite, Szaszka, Banat. Quoted by W. C. Brögger, *Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtirol*, 1895, p. 62. Analyst, Th. Scheerer.

III. Quartz-monzonite (banatite). Sultan Mountain, near Silverton, Colorado. Analyst, L. G. Eakins.

IV. Augitic monzonite. Babcock Peak, La Plata Mountains, Colorado. Analyst, H. N. Stokes.

V. Monzonite. Monte Mulatto, Tyrol. Quoted by W. C. Brögger, *loc. cit.*, p. 62. Analyst, Lemberg.

VI. Monzonite. La Plata Valley, above Basin Creek, La Plata Mountains, Colorado. Analyst, W. F. Hillebrand.

The position of the Rico monzonite is near the two rocks from the La Platas. If these analyses be compared with others discussed by Brögger in the publication from which two partial analyses have been quoted it is still more plain that the rocks in question are typical members of the groups to which Brögger has given the names monzonite and quartz-monzonite or banatite.

PORPHYRIES ASSOCIATED WITH THE MONZONITE.

A group of porphyries of obscure occurrence has been observed in the landslide area of Darling Ridge. None of them is represented on the map because they were seen only in dislocated blocks, and none could be traced sufficiently to establish its relations to the stock. The area in which the rocks in question were particularly noted is to the east of the South Fork of Horse Gulch and in the main gulch a little below the forks. In this vicinity there are in the more or less broken-up blocks many small exposures of porphyries characterized by green augite, by feldspars exhibiting a micropertthitic intergrowth both in phenocrysts and in groundmass particles, and in some cases by considerable quartz. As an extreme form may be cited the rock penetrated by several tunnels on the south side of Horse Creek not far below the south fork. In these rocks there is sometimes but little plagioclase, and certain ones can only be called syenite-porphyries. At a small ledge outcrop the rock is almost granular, with but little augite and biotite and no hornblende.

These alkali-rich rocks do not extend out of the landslide area, except possibly in the basin of the South Fork of Horse Gulch, where they are concealed by talus and wash. Much of the material of "The Blowout" is of these rocks intimately associated with monzonite, but in the crushed and greatly stained condition of all the rock in this vicinity no clear idea was obtained as to the relative importance of the two types. It is considered probable that the monzonite stock rock is cut by the alkali-rich porphyries.

HORNBLENDIC MONZONITE-PORPHYRY.

General description.—The intrusive sheets and dikes occurring in the Rico Mountains are nearly all of one chemical and mineralogical type, but present many minor structural variations, which were no doubt caused by slight local differences in the conditions attending their consolidation. The structural modifications do not obscure the similarity in composition when the rocks are studied under the microscope, but some masses are too fine grained for the unaided eye to recognize their constitution with certainty, and decomposition often renders the character obscure.

The rock of the larger sheets and of many dikes is a very distinct porphyry of general light-gray tone with an even balance between phenocrysts and groundmass. The most abundant phenocryst is a plagioclase, determined in some cases to be labradorite ($Ab_1 An_1$), developed in the common stout prismatic crystals. Dark green hornblende in small prisms is the only other constant and essential phenocryst. Small quartz crystals, almost invariably well rounded by resorption, are sparingly present in a few cases, but can usually be

detected in the hand specimen only on close scrutiny with a lens. The gray and homogeneous-appearing groundmass consists of orthoclase and quartz.

The most striking variation in structure noticeable in these rocks arises from the development of the plagioclase phenocrysts. These are much more abundant than hornblende and, as a rule, are larger. But they may be nearly uniform in size or present a gradation from the largest to those scarcely distinguishable by the naked eye. In the Montelores sheet, for example, the plagioclase crystals are uniformly of 2 to 3 mm. diameter wherever that mass was examined. More commonly there are numerous crystals of 5 mm. or more, though seldom reaching a size of 1 cm. in diameter. The common color of the plagioclase is white, and the centers of the larger ones may be clear and glassy. In many places the crystals have become clouded by ferritic particles and muscovite.

The composition of the plagioclase crystals in the Rico porphyries is not so easily determined as in many similar rocks. Carlsbad twins are rare, hence the Michel Lévy method of identification is inapplicable. But the extinction in the zone normal to the albitic lamellae reaches 20° in many instances noted, from which it may be inferred that labradorite ($Ab_1 An_1$) is abundant. As the same variety was found common in similar porphyries of the La Plata Mountains it is believed that labradorite is the common phenocryst in the Rico monzonite-porphyries.

The hornblende of these porphyries is always of the common green variety. In many masses it is developed only in distinct prisms, which are, however, always smaller than the plagioclase and subordinate in amount, but in several cases a considerable part of the hornblende is in so small prisms that it either obscures the groundmass or at least gives a dark tone to the rock. None of the hornblende belongs to the groundmass period of consolidation, as may be clearly seen under the microscope.

The accessory constituents of these porphyries—magnetite, apatite, titanite, and allanite—occur in small phenocrysts, often distinguishable to the naked eye. Magnetite alone occurs usually in two generations, the earlier and larger grains being occasionally included in plagioclase and the fine dust of the later period being disseminated evenly through the groundmass. Magnetite is the most abundant of these accessories, but yet is quantitatively of little importance. Apatite and titanite play the rôles usual in such rocks. Allanite appears in single small prisms in several thin sections and is probably sparingly present in all the masses.

No augite or biotite has been observed in any of these porphyries. They are hornblendic rocks, and differ thus very constantly from the dike porphyries associated with the monzonite stock and from the

soda-rich, quartz-free monzonite-porphyry occurring in a large dike crossing Bear Creek and the Dolores River near the mouth of the former.

The groundmass of this hornblende monzonite-porphyry consists chiefly of orthoclase with a subordinate amount of quartz. Plagioclase enters into its constitution in only two or three observed cases, and in those instances quartz was not determinable. The structure is often evenly fine grained, the component minerals occurring in separate particles. In the coarser developments of this structure quartz may show a tendency to regular form. The presence of quartz is made distinct in many rocks by the cloudiness of the orthoclase grains, contrasting with the clearness of the quartz.

Not infrequently the grains of the groundmass are comparatively large, but the two minerals are intergrown in complex and apparently irregular manner, producing a patchy modification of the micropoikilitic structure. This is generally evident only between crossed nicols, and, if there are quartz phenocrysts present, aureoles of oriented quartz filled with dusty orthoclase are always found about them. The groundmass grain often varies without regard to the visible size of the porphyry bodies; still, the narrower dikes and thinner sheets are commonly of very fine grain. An uneven development of the groundmass particles is found in numerous cases.

Decomposition products.—Decomposition of these porphyries greatly obscures the constitution to the unaided eye, but seldom prevents clear recognition of their characters under the microscope. Hornblende is frequently entirely decomposed and replaced by a mixture of chlorite, calcite, quartz, and ferritic hydrates in varying proportions. The chlorite gives the rock a dull-green hue and obscures its composition when deposited secondarily in particles throughout the groundmass.

The feldspars are always more or less clouded in the common manner, and this may add to the distinctness of the porphyritic structure if the orthoclase in the groundmass is chiefly affected. It then is usually dull pinkish and causes the white labradorite phenocrysts to stand out in increased prominence. On the other hand, if both feldspars are equally affected the phenocrysts become scarcely distinguishable from the groundmass. Calcite is common in small amount. Epidote may develop either from hornblende or in the mass of plagioclase crystals, as has often been described.

Relationships of this porphyry.—The predominant porphyry of the Rico Mountains, above described, is practically identical with many of the rocks occurring in the Henry, Carriso, El Late, and La Plata mountains and in many places in Colorado. In a description of these rocks by the writer,¹ published some years ago, they were called

¹ The laccolitic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, pp. 157-241.

"hornblende-porphyrite" in the sense of diorite-porphyrity, the more prominent development of the plagioclase being considered as sufficient ground for assigning the rock to the diorite family. But with the establishment of the monzonite family it is clear that a large number of the rocks of the Henry Mountains and other laccolithic groups are porphyritic members of that intermediate family. The same type of porphyry occurs in many places in Montana and has been described under various names—by Iddings from the Yellowstone Park,¹ and by Pirsson from the Little Belt² and Judith³ mountains.

In the table below is given a list of analyses of porphyries very similar to the Rico monzonite-porphyrity so far as the feldspars are concerned, though showing some variation in the amount of quartz and in the dark silicates, biotite and sometimes augite accompanying the hornblende.

Analyses of quartz-bearing monzonite- and diorite-porphyries.

[Analyst, W. F. Hillebrand.]

Constituent.	I. Diorite-porphyrity, Deadwood Gulch, La Plata Moun- tains.	II. Monzonite-por- phyry, Revet Crag, Mount Hil- lerys, Henry Mountains.	III. Monzonite- porphyry, Sierra Carriso.
SiO ₂	60.44	62.88	63.18
Al ₂ O ₃	16.67	17.13	16.47
Fe ₂ O ₃	2.31	1.86	2.36
FeO.....	3.09	2.58	2.28
MgO.....	2.18	1.48	1.33
CaO.....	4.22	5.39	4.77
Na ₂ O.....	5.18	4.50	4.40
K ₂ O.....	2.71	2.25	2.93
H ₂ O below 110°.....	1.43	.16	.27
H ₂ O above 110°.....		.42	.60
CO ₂.....	.48		
TiO ₂.....	.60	.51	.60
P ₂ O ₅.....	.29	.26	.28
MnO.....	.13	.16	.15
BaO.....	.12	.16	.15
SrO.....	.11	.12	.09
Li ₂ O.....	Trace.	Trace.	Trace.
Total.....	99.96	99.86	99.86

¹Geology of the Yellowstone National Park: Mon. U. S. Geol. Survey, Vol. XXXII, Pt. II, 1899, pp. 94-97.

²Petrography of the igneous rocks of the Little Belt Mountains, Montana, by L. V. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. III, 1900, p. 518.

³Geology and mineral resources of the Judith Mountains of Montana, by W. H. Weed and L. V. Pirsson: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, p. 562.

PORPHYRY OF CALICO PEAK AND VICINITY.

A rock of unusual character was found occurring in dikes in the vicinity of Calico Peak and probably forming an important part, if not the whole, of the alunitized cone of that mountain itself. It has been given a special color on the map. This rock is a porphyry of most marked appearance, characterized by large orthoclase phenocrysts in considerable abundance, some of them exceeding an inch in length. Associated with these prominent crystals are many smaller ones of plagioclase and augite, biotite, or hornblende. Quartz crystals are rare. The groundmass of these porphyries is quite different from that of the common sheet rock. It has much plagioclase and little or no quartz. On the whole it is estimated that the rock is much nearer the stock monzonite in composition than would be inferred at first sight. In the development of green augite and brown biotite there is a further link connecting this peculiar type with the monzonite. None was sufficiently fresh for analysis, but it is probable that the rock is somewhat richer in alkali feldspar than the monzonite, and hence approaches a quartz-bearing syenite-porphyry.

In point of time these dikes cut the earlier and common monzonite-porphyry, but have not been observed in contact with the granular stock rock nor with the basic dikes soon to be described. The rock of Calico Peak has not been found in sufficiently fresh condition to allow of its certain reference to this type, but it is plain in many places that it bore large feldspar crystals, and it is also known that dikes of the rock in question in Bull Gulch have undergone alteration like that of the Calico Peak rock and in such cases resemble the latter very closely.

BASIC DIKE ROCKS.

The geological map represents a number of basic dike rocks occurring sparingly in various parts of the Rico Mountains, and a few others were observed in small exposures. These dikes are seldom more than a few feet in width and their length is apparently not great, though none of them has been accurately traced to its end. They are often irregular in course and are effectually concealed by slight coverings of débris, for they do not often form projecting ribs. The most prominent of these basic dikes is that shown on the eastern border of the area. This has been traced to the northeast over the crest of the divide between Barlow Creek and the Silver Creek drainage, and it exceeds 20 feet in width in some places.

Rocks similar to these occur in the La Plata Mountains, in the Durango, Engineer Mountain, and Telluride quadrangles, and, in fact, all over the country adjacent to the San Juan Mountains, as far as it has been carefully explored. There is much more variety among

these dikes than is represented at Rico, where one type prevails to an unusual degree. In spite of the variations these rocks are apparently connected in origin with the intrusive sheets and stocks of monzonitic magmas described above. They cut all other rocks and are distinctly the latest igneous masses of the region.

From their constant association with monzonite- and diorite-porphyrries in southwestern Colorado these rocks might be assumed to be *melanocratic diachistic* dikes, according to the genetic classification of Brögger, but it must be confessed that the complementary *leucocratic* magmas required by such an assumption did not come to eruption in the Rico Mountains. From the great variety of these basic dike rocks in southwestern Colorado it would appear that nearly all the known kinds of lamprophyres or melanocratic dike rocks may be present.

The basic dike rocks of the Rico Mountains are closely related as far as can now be ascertained, but few are fresh enough to allow an accurate determination of their normal composition. The ferromagnesian silicates greatly predominate, common greenish augite being the most constant and abundant, with variable amounts of olivine, reddish-brown biotite, and brown camptonitic hornblende. Magnetite is present rather sparingly. The feldspathic constituents are partly orthoclase, partly plagioclase, and analcite may have been present in some cases, being now largely replaced by secondary products. The habit of the freshest rocks is decidedly basaltic, through the abundance and form of development of augite and olivine.

From the comparatively subordinate rôle ordinarily played by plagioclase, these rocks fall in the group named by Rosenbusch olivine-bearing *augite-rogesite*.

PHENOMENA OF INTRUSION.

PORPHYRY MASSES.

Centers of eruption.—It is clear from an inspection of the geological map that while the porphyry sheets have a general concentric distribution about the center of uplift, they are specially numerous in the two groups of peaks into which the Rico Mountains are divided by the Dolores Valley. There are but very few sheets present in the valley itself at the stratigraphic horizons in which they are most abundant on either side. The Montelores sheet is a notable exception to this rule.

On the west side of the dome the porphyry masses are most numerous in the semicircle of peaks from Expectation Mountain around to Sockrider Peak. The greatest number of observed irregularities in the sheets, such as crosscutting and forking, is also to be found in these summits. It therefore seems plainly indicated that the principal source of these masses is the complex of dikes situated in the center

of this semicircle at the forks of Horse Gulch, but unfortunately the exposures of this interesting locality are very restricted.

In the canyons of the three forks of Horse Gulch porphyry forms rugged cliffs seeming at first to belong to a large mass, but in the north fork in particular a close scrutiny reveals the fact that there is a very complicated interlacing of dikes, of which the drawing of the map is but a poor generalization. The sedimentary rocks are found in strips or angular blocks between dikes, and form but a small part of the exposures. Since all the rocks of this vicinity have been thoroughly impregnated with pyrite and stained by its decomposition products, it is necessary to examine the cliff faces foot by foot to recognize the form and extent of the porphyry masses. In general the dikes of the north fork have a prevalent north-south trend, with many intersections.

To the south these dikes pass under the alluvium of the valley bottom, and in their strike, in the gorge of the south fork, is a mass of porphyry apparently much more continuous than that above described. But the exposures are here more limited, and beyond the actual borders of the gorge the outlines of the porphyry are effectually concealed, as shown by the map.

In the middle or west fork of Horse Gulch a large series of dikes is revealed in the walls of the little canyon. These trend nearly east and disappear under the soil and forest growth, which comes to the brink of the gorge. It is probable that these dikes are offshoots from the mass of the south fork, a relation indicated by the poor outcrops of sandstone alternating with porphyry at the mouth of the latter on the west side. The drawing of the map is much generalized in the representation of all these dikes, for not only are they obscure, but there is such a network that a much larger scale is necessary for their accurate delineation.

In spite of the poor exposures, it is plain that at the forks of Horse Creek is the most notable eruptive center of the porphyry magmas to be found in the Rico Mountains, and by its relation to the sheets of the adjacent peaks it seems likely that here is the principal channel through which the magmas of the latter ascended to the horizons of lateral intrusion. On the east side of the north fork the connection between two sheets and the dikes was found to be well exposed, and on that basis the other sheets found to approach closely to the dikes of the canyon are also represented as offshoots.

The various dikes and sheets of this center belong for the most part to the common type of hornblende monzonite-porphyry, varying only in grain, but on the North Fork of Horse Creek a somewhat darker type of finer grain was observed to cut the prevalent variety in dikes and to send off thin sheets on both sides. This facies is actually but little different in composition from the principal form.

On the east side of the Dolores the porphyry sheets are most abundant in the vicinity of Blackhawk Peak, but no center of eruption at all corresponding to that of Horse Gulch has been found. It is possible that the porphyry mass of the lower part of Allyn Gulch is a crosscutting body, but no evidence to that effect was obtained, and it seems more probably a part of the Newman Hill sheet.

The magna of the sheets in the eastern part of the Rico dome may possibly have come up through fissures on the border of the dome. In this case they have been deflected to stratigraphic horizons on reaching the Dolores formation. In this connection it may be pointed out that the largest mass of monzonite-porphyry known in the region occurs but a few miles to the northeast, beyond the influence of the Rico uplift, in Hermosa Peak and Flattop.

Stratigraphic distribution of sheets.—The observed sheets of the Rico Mountains represented on the map are evidently most numerous in the Dolores formation. Instances are not wanting of their occurrence both above and below the Dolores, but especially for the lower horizons the few sheets present in the Rico and Hermosa formations only serve to emphasize the preponderance noted. It is rather singular that sheets are not more numerous at the soft shale horizons between the massive limestones of the Hermosa. Possible reasons for this distribution are given in the next section.

As to the occurrence of sheets above the Dolores formation, it must be confessed that data upon this point are wholly wanting on the eastern side of the river and that the mass of Elliott Mountain proves that at least some masses did reach above the base of the La Plata sandstone. In the similar group of the La Plata Mountains a great many sheets occur in the Juratrias and also in the Cretaceous, although the principal horizon of intrusion is there, as here, in the Dolores formation. It must be assumed as probable that at least a few sheets were intruded into the Cretaceous beds of the Rico dome.

The relation of the sheets to the Rico dome structure is discussed in Chapter IV.

Small dikes.—There are many small dikes and tongues of porphyry in the vicinity of the larger sheets. Many of these are above larger masses, and it has been generally assumed that they represent minor arms or offshoots, such as must occur in the fissured sedimentaries adjacent to the principal masses, rather than the main feeders or channels through which the magmas of those larger bodies ascended. It is true that neither observation nor theory demands that the conduit supplying the material for a large intrusion should be of corresponding size, and some instances were observed where a narrow dike seemed to be the supply channel for a large body.

MONZONITE STOCK.

Form and dimensions.—Although the actual contacts of the large stock of Darling Ridge are revealed in but few places, and much of it comes within the landslide area, it is believed that the outlines of the mass and its relations to adjacent rocks are correctly understood. The northern limit of the stock is in the bed of Horse Creek, a short distance below the forks. From this point it extends nearly 2 miles southeasterly to the base of the prominent ridge between Sulphur and Iron gulches, and its maximum breadth of about three-fourths of a mile is between these gulches.

On the crest of Darling Ridge a tongue of sediments with a porphyry sheet crosses from the southeast onto the Horse Gulch slope between two masses of monzonite. It is impossible to make out definitely in the confusion of the landslide surface whether the smaller body of monzonite is a branch of the main stock or is separated from it by the sedimentary arm. In all probability the former is the case, and if the contact of the stock were laid bare many other projecting arms would no doubt be exposed.

Relation to porphyry sheets.—The stock was seen to cut off porphyry sheets in a few places, but the view that it is distinctly later than all the porphyries of the main type is based principally upon the relations exhibited in the La Plata Mountains between stocks of a very similar monzonite, as well as others of diorite and syenite, to hornblende monzonite-porphyry in intrusive sheets. There the stocks cut across all sheets in their courses. The diorite-monzonite and other stocks of the Telluride quadrangle also cut intrusive porphyries of the same general character as the Rico porphyry.

PHENOMENA CONNECTED WITH IGNEOUS INTRUSION.

In the introductory chapter it was pointed out that the intrusion of molten magmas in the area of the Rico Mountains had been accompanied by phenomena of contact metamorphism about the monzonite stock and followed by local solfataric action at Calico Peak.

Contact metamorphism.—The sedimentary rocks adjacent to the porphyry sheets and dikes are often somewhat indurated, but seldom exhibit pronounced mineralogical changes. About the monzonite stock, on the other hand, a high degree of metamorphism has taken place; limestones have become marbleized and several silicates of lime, magnesia, iron, and alumina have been formed. Of these garnet is the most common, while various pyroxenes and amphiboles are also abundant. Specular iron is very common accompanying these silicates, and the magnetite deposit found in the shattered limestones on the north side of Darling Ridge may possibly be classified with the

products of the metamorphic epoch. Almost the entire area of the contact zone about the monzonite stock is greatly obscured by landslide and other surface débris.

The association of contact metamorphism with stocks of granular rocks has been observed by the writer at a number of localities in Colorado, and the absence or slight amount of such action in the vicinity of large laccoliths of porphyritic rocks has been a most striking fact. In no case has any considerable development of garnet, vesuvianite, pyroxene, or amphibole been noted in the contact zone about porphyry intrusives corresponding to the granular stock rocks. Since in the La Plata Mountains, as well as at Rico, the porphyries and the granular rocks are similar in chemical composition but differ in structure and mode of occurrence, the suggestion is natural that there is some genetic relation between the process of metamorphism, the development of the granular structure, and the stock form of eruption. The further discussion of this relationship will be reserved for a review of the observed occurrences of stock rocks in Colorado, which it is the writer's desire to complete at no distant day.

Solfataric action. The alteration of the porphyry of Calico Peak into a rock consisting largely of alunite, a hydrous sulphate of alumina and the alkalis, has already been referred to in Chapter I. This alteration can be explained only as the result of the attack of sulphurous agents, and from the circumstances of occurrence there can be no doubt that the action is to be attributed to solfataric emanations of the Rico eruptive center in the period of waning igneous activity.

The cone of Calico Peak is made up of a light-colored rock which is either nearly white or stained various shades of red and yellow, often in brilliant hues. The rock has either a marked porphyritic structure or is highly brecciated. No contacts were seen, owing to the extensive talus slopes which conceal it on all sides, as represented in Pl. VII. The alteration is so extreme that it is not certain that all of the rock belongs to a single mass, though it is apparently of that character.

The rock of the greater part of the peak was plainly porphyritic and contained many large feldspar crystals, and from this fact it is supposed that the rock was originally of the type of monzonite-porphyry with large phenocrysts of glassy orthoclase, which has been described above and which occurs in fresh form only in the vicinity of Calico Peak in long dikes represented on the map. In its present condition the rock of the peak contains no dark silicates; the former feldspar phenocrysts are represented either by a mass of white kaolin or by a granular mass of a nearly colorless mineral, ordinarily too fine-grained for recognition. The groundmass is grayish in tone and may be fine or coarse grained. In some places the rock has become largely a porous quartzitic mass. The room of the larger feldspar crystals is seldom completely filled by the alteration product, which usually

appears as an aggregate of rude plates, a definite crystal outline being, however, rare. These plates are rough crystals of alunite, the basal plane predominating and being bordered by the low hemihedral pyramid commonly developed in this mineral. No good crystals of polished faces were found.

At several places the freshly fractured rock was found to exhibit a very distinct yellow color in the porous areas representing feldspar phenocrysts, the color being due to native sulphur in minute round crystalline particles.

The more massive rock found in many places consists of a coarse-grained aggregate of irregular rude tablets with kaolin filling the interstices. Small veins of uniform fine grain also traverse the rock locally, the character of the material being unrecognizable megascopically.

The general character of the Calico Peak rock was recognized by the writer from its resemblance to the quartz-alunite rock found by him in the Rosita Hills, Custer County, Colorado. In the latter case the material was formed by solfataric action upon rhyolite in a small volcanic center,¹ and the alunite made up a much smaller part of the rock than at Calico Peak. But fairly good crystals were found in the Rosita Hills, associated with diaspore.

Microscopical study of the Calico Peak rocks confirms fully the identification of the principal substance of the Calico Peak mass as alunite; and shows that kaolin and quartz are the only other minerals of importance present in the specimens examined. Diaspore has not been certainly identified in these rocks, and the chemical analyses given below show that there can be but very little present.

In the table on the following page are presented quantitative analyses of two of the Calico Peak specimens and one of a rock from the Rosita Hills. I is the analysis of a coarse-grained rock almost resembling a pearly gray marble from the west slope of Calico Peak. II is a fine-grained white vein on the south ridge of the peak. III is an alunite-quartz rock from Mount Robinson, in the Rosita Hills, republished from the descriptions cited above. Analyses I and II are by George Steiger and III was made by L. G. Eakins, all in the laboratory of the Geological Survey. In the column following each analysis is given the molecular ratio.

¹ Geology of Silver Cliff and the Rosita Hills, Colorado, by Whitman Cross: Seventeenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1896, pp. 52-56. On alunite and diaspore from the Rosita Hills, Colorado: Am. Jour. Sci., 3d series, Vol. XLI, 1891, pp. 466-475.

Analyses of alunite rocks.

Constituent.	I.		II.		III.	
SiO ₂	2.54	42	1.79	30	69.67	.....
SO ₃	35.24	440	37.92	474	9.27	114
Al ₂ O ₃	42.35	415	37.66	370	13.72	134
CaO .....	.08	.....	.38	.....	.07	.....
Na ₂ O	4.02	65	2.12	34	.34	32
K ₂ O	3.27	35	6.77	72	2.44	
H ₂ O below 110° .....	.13	.....	.06	.....	4.73	263
H ₂ O above 110°	11.99	666	13.03	724		
Total	99.62	.....	99.73	.....	100.24	.....

a Contains TiO₂ and P₂O₅, if present.

From the molecular ratios of I and II it appears that the substances analyzed consisted mainly of alunite with a little kaolin. The alkalis are a little below the required amounts for the sulphuric acid found, but if the losses of the analyses be assumed to be soda, and the lime be supposed to replace alkali in alunite, the analyses are very satisfactory. It is notable that the vein alunite (II) is much richer in K₂O than the replaced rock (I).

The alunite-bearing rock of the Rosita Hills contains a great deal of quartz, but the Calico Peak mass is, in some parts at least, nearly pure alunite.

COMPARISON OF THE RICO MOUNTAINS WITH LACCOLITHIC CENTERS OF ERUPTION.

The laccolithic mountain groups.—From the western summit of the Rico Mountains the observer has spread out before him a plain country, dotted with widely separated groups of peaks, which has become celebrated the world over for its examples of the laccolithic type of intrusion of igneous magmas into sedimentary rocks. In the far distance, and visible only when the atmosphere is especially clear, lie the Henry Mountains, which will always be classic ground for the student of the laccolith.¹ Nearer to the point of view are the Abajo or Blue Mountains, the La Sal, El Late, and Carriso groups, and, close at hand, the La Plata Mountains. In all of these groups of mountains the igneous rocks are similar in character as well as in their intrusive forms of occurrence, as has been definitely shown by the writer in a review of the observations made in the early explorations of the Powell and Hayden surveys, with descriptions of the rocks collected by Gilbert,

¹ Geology of the Henry Mountains, by G. K. Gilbert

Holmes, and others.¹ Since that review was published opportunity has been afforded the writer to study in detail the La Plata Mountains and parts of the San Miguel Mountains and to examine other localities in which the laccolithic type of porphyry occurs. Additional material representing the rocks of the Henry and Carriso mountains has also come into his hands.

At the time of the review above mentioned all the available rock specimens from the Henry, Abajo, El Late, Carriso, and San Miguel mountains collected by the earlier geological explorers were of one structural type of porphyry, and exhibited no great range in mineralogical composition. They were described as "porphyrites," mainly hornblendic and quartz bearing, but having a considerable amount of orthoclase in the groundmass in every case. It is now evident that most of these rocks are monzonite-porphyrries or *orthoclase-bearing diorite-porphyrries*.² Additional material from the Henry Mountains, collected by Prof. Marcus E. Jones, and from the Carriso Mountains, collected by Mr. C. R. Corning, fails to reveal the presence in these groups of other types of porphyry than those already known.

The only granular rock collected from the mountain groups in question, by either Gilbert or Holmes, was by the latter from the La Platas, but its mode of occurrence was not distinguished from that of the porphyries. The recent investigation of that group has shown that the specimen in question came from a stock of monzonite in the heart of the mountains, and that both syenite and diorite are also present in stocks. All of these granular rock masses of the La Platas cut many intrusive sheets of diorite- or monzonite-porphyry. Thus it appears that one of the groups supposed by Holmes to be like the Carriso, El Late, and Abajo mountains, and due to injection of porphyry sheets, is in reality more complex in its igneous history.

The San Miguel Mountains were also classified by Holmes among the groups of summits due to great intrusions in Cretaceous shales, and the specimens collected by him in Lone Cone and other western summits indicate that his idea is true in part. But the detailed survey of the Telluride quadrangle revealed that the Mount Wilson or

¹The Laccolithic Mountain Groups of Colorado, Utah, and Arizona, by Whitman Cross: Fourteenth Ann. Rept. U. S. Geol. Survey, Pt. II, 1894, pp. 157-241.

In this article the terminology of Gilbert was followed in the word *laccolite*, but since its publication the writer has become convinced that the form *laccolith* is preferable, both from the etymology and to avoid correspondence with the ending of mineral and rock names.

²The writer approves most heartily of the usage now common in America by which the word porphyry and all of its derivatives are reserved exclusively for the designation of rock structure. Certain of the laccolithic rocks are intermediate between quartz-bearing monzonite-porphyry and quartz-bearing diorite-porphyry. They thus become porphyritic equivalents of granodiorite, as recently defined by Lindgren (Am. Jour. Sci., 4th series, Vol. IX, 1900). While the writer believes that the rocks to which the name granodiorite is applied by Lindgren must be recognized by a distinct name, that term seems to him objectionable, since the rocks are not in fact intermediate between granite and diorite—the conception expressed in the name—but between quartz-monzonite (banatite) and tonalite. If granodiorite be finally accepted by petrographers, many of the laccolithic rocks of the Great Plateau region must be called granodiorite-porphyry.

eastern group of the San Miguel Mountains was due to a great stock of diorite-monzonite cutting andesitic tuffs of the San Juan series and the Eocene (?) San Miguel formation, and hence that these peaks are in fact geologically a part of the San Juan Mountains, cut off by erosion. A hasty examination by the writer in 1899 of Dolores Peak, lying between Lone Cone and Mount Wilson, showed the presence at that point, also, of tuffs and underlying San Miguel beds, besides some porphyry masses and crosscutting bodies of granular rock, from which it appears that this mountain is more closely related to the San Juan Mountains in origin than to the laccolithic groups, as supposed by Holmes.

Stocks and laccoliths of the Telluride quadrangle.—The Mount Wilson stock does not occur in close association with intrusive porphyries and is but one of a number of large stocks of monzonite, diorite, or gabbro, now known to cut the volcanic series of the western San Juan Mountains. These stocks are independent of centers of laccolithic intrusion or of local uplift of domal character. But large laccoliths of diorite- or monzonite-porphry do occur in the same general region, as in Grayhead, Whipple, and Hawn Mountains, and in Flatop, a few miles northeast of Rico. These laccoliths are all in the Cretaceous shales and there is no folding or faulting of the underlying strata.

In the case of both the stocks and the laccoliths of the Telluride quadrangle there is no apparent reason, such as structural weakness in the crust, for the eruptions at the points where the masses are found.

Relations of the Rico Mountains.—The Rico Mountains are related to all the groups of laccolithic mountains mentioned above in that they contain a large number of intrusive sheets of the common types of porphyry occurring at a center of local uplift, with which the intrusions themselves have had more or less to do. But their most intimate relationship is to the La Plata Mountains, the only other center in which crosscutting stocks of granular rocks are known to occur. The stock rocks are in both cases similar in chemical composition to the sheet porphyries, but represent later eruptions of very different physical conditions.

But while the Rico Mountains are in some respects much like the La Platas in the occurrences of porphyries and granular stock rocks, they are unlike any other center of eruption with which they have been compared in the variety and extent of the volcanic phenomena exhibited and in the principal elements of the local structure. In Chapter IV will be found a discussion of the Rico dome and of the rôle played by the eruptive rocks in its formation, from which it will appear that the structural features are not chiefly due to igneous intrusion, and that the intrusions may even be regarded as due to the earth stresses which have produced the principal structure. This

conclusion rests upon the insufficiency of the exposed igneous masses to produce the structure seen, the improbability of the existence of hidden masses of importance, and the abundant evidence of fault blocks thrust up in the heart of the dome since the porphyry intrusions.

The solfataric activity and the later spring action of the Rico center may be due to proximity to the great volcanic center of San Juan or to the fracturing of the rocks in the period of faulting. Possibly also the deeper dissection of the dome by erosion has revealed the action of agents which have been, to some extent at least, in operation at corresponding depths at other centers.

From the character of the Rico and La Plata mountains it is evident that the La Sal, Abajo, El Late, and Carriso groups must be reexamined in some detail before the conclusion that they are genetically of the simple laccolithic origin ascribed to the Henry Mountains by Gilbert can be finally accepted.

CHAPTER IV. STRUCTURE OF THE RICO DOME.

By WHITMAN CROSS and ARTHUR COE SPENCER.

INTRODUCTION.

The stratified rocks of the Rico district have been described in a preceding chapter, from the lowest Paleozoic known in the region to the base of the Dakota Cretaceous. In thickness, however, these rocks represent only about half of the known section of southwestern Colorado, reckoned to the top of the Laramie. The thickness of the strata exposed in the vicinity of Rico may be given as approximately 5,300 feet, as shown in the following table.

Strata exposed in vicinity of Rico.

	Feet.
Dakota	150
McElmo.....	600
La Plata.....	250
Dolores.....	1, 800
Rico	300
Hermosa	1, 800
Devonian.....	400
Total.....	5, 300

The thickness of the higher Mesozoic strata in adjacent regions, as will be brought out in the forthcoming folios of the La Plata and Durango quadrangles, is approximately 4,700 feet. If, then, as seems probable, all these higher formations originally extended across the site of the present San Juan Mountains, the sedimentary section, in the western part of the region at least, was no less than 10,000 feet in thickness. There is every reason for supposing that the whole of this thickness covered the site of the Rico Mountains at the close of the Mesozoic. Continental uplift was succeeded by enormous erosion in the area of the San Juan Mountains, but there are reasons for supposing that about 2,000 feet of the Cretaceous beds remained in the vicinity of Rico to be covered by Tertiary volcanic rocks, like those still preserved in the adjacent parts of the San Juan Mountains to the east and

north. About that thickness of Cretaceous shales is exhibited under the volcanics in Mount Wilson, only 9 miles directly north of Rico.

While there are evidences of several important orographic disturbances in the San Juan region prior to that at the close of the Laramie, the most notable structures now visible in the sedimentary beds about the mountains are due to that movement. There have been other movements since the eruption of the Tertiary volcanics, and one of the most interesting problems which this region presents is connected with the recognition of these later periods of deformation and the differentiation of their effects. Unfortunately, in the case of the Rico dome there are no intrinsic data for determining its age relative to the broader structures observed; so far as the facts there presented are concerned the quaquaversal fold might have been formed at any time since the deposition of the highest rocks involved—the Mancos shales. Consequently, all age determinations applied to this feature are founded upon the general geological data of the region, and especially on facts concerning the age of the igneous rocks.

THE BROAD SAN JUAN STRUCTURE.

San Juan dome.—The San Juan Mountains are flanked upon the south, west, and north by sedimentary formations which dip away from the central mountainous mass of crystalline and semicrystalline rocks. Upon the east the relations are not well known, but so far as the evidence goes it indicates that such strata as have escaped erosion dip toward the east, or that in their absence the surface of the granite upon which they once rested slopes in this direction.¹ The structure is thus seen to be that of a broad quaquaversal fold. Its diameter in an east-west direction along a line drawn through Rico and the central portion of the Needle Mountains and thence to the Piedra River is upward of 60 miles, and the amount of arching along this line, estimated from a restoration of the Dakota sandstone, is approximately 10,000 feet, an amount equal to the thickness of the Paleozoic and Mesozoic formations involved. Upon the Rico side this amount of depression of the Dakota is reached between the two branches of the Dolores, but slight northwestward dips continue for many miles beyond this into the gently warped plateau region, which as a physiographic province may be separated from that of the San Juan Mountains in a somewhat arbitrary manner on some line of steeper dips. Thus, on approaching the mountains from the west it is seen that the surface of the Dakota is cut through by deep canyons as it rises gently toward the center of uplift until, along a general course adjoining the La Plata and Rico mountains, the beds begin to rise more steeply under the immediate influence of the San Juan dome. The dissected table-lands

¹ For the general structure of this region see the Atlas of Colorado, Sheet XV, Hayden Geol. and Geog. Surv. Terr., 1877.

of the west may be considered as a part of the Plateau region, while the more diverse topographic forms to the east are naturally placed in the mountain province.

The San Juan uplift must be regarded as a regional expression of continental movements which have occurred since the deposition of all or nearly all of the Mesozoic. The first great uplift preceded the deposition of the San Miguel conglomerate;¹ another is witnessed in the upturning of Tertiary beds of Puerco² (Eocene) age south of Durango, and this or still another upward movement is indicated by the attitude of the San Juan formation upon the north side of the Needle Mountains in the headwaters of the Rio Grande and in the tilting of water-laid beds occurring in the volcanic complex of the Silverton region.

It is suggested as an hypothesis for future corroboration, but for which indications such as above noted are not entirely wanting at present, that the doming of the San Juan region has been the result of successive deformations in the same direction, repeated at each period of continental uplift affecting this and adjacent regions.

Rico and La Plata domes.—The structure of both the Rico and the La Plata mountain groups is quaquaversal. Each is a dome which locally affects the structure of the broader San Juan dome near its periphery. Neither of these smaller domes is symmetrical, for in partaking of the general structure each has added to the dips of the larger dome upon the outside and has tended to neutralize them upon the inside. Thus, in the case of the La Plata dome notable local dips are wanting upon the northeast side, and in that of the Rico structure they are low or absent upon the east and southeast; consequently both domes open out toward the central mountain mass of the San Juan.

Relation of local domes to larger structure.—The Rico and La Plata secondary domes are probably genetically related to the broader San Juan structure, though how close the relationship may have been can not now be determined, since the interconnection of igneous intrusion and continental and orogenic uplift of the Rocky Mountain type is not yet understood. In both cases the preservation of the mountains as regions of high topographic relief is due to the presence of igneous rocks which have been more resistant to erosion than the sediments would have been alone. The intrusions are in the form of stocks, dikes, and sheets. To the latter, which may in cases have sufficient thickness to be of the type known as laccoliths, a certain amount of the observed deformation of the stratified rocks is certainly due. In the La Plata Mountains the mass of intruded matter of this nature shown in the horizons exposed is comparable to the deformation they have suffered over and above that affecting the lower formations, which are covered and therefore beyond observation, so

¹ See Telluride folio.

² See Hayden map, loc. cit.

that if the porphyry included in the hidden strata should bear the same proportion to the sedimentary rocks as in the observed section, the doming would be accounted for without additional uplift. At Rico the structure and make-up of the dome is much better exhibited, and though a working hypothesis that the observed structure might be due to a huge laccolith lying between the Algonkian and the Paleozoic rocks was at one time entertained, it is now known that such a mass of igneous rock does not exist, and that the amount of deformation which the uppermost strata of the region underwent was several times in excess of the amount of igneous material which was intruded into the strata below them; that is, the formation of the Rico dome is mainly due to a central uplifting force, apart from any actual intrusions of liquid rock material. That such a force was also active in the La Plata uplift may well be believed, for there, as at Rico, the thickest laccoliths or sills occupy a zone, so far as the rocks now remaining are able to show, at a distance from the center of the dome, and it is upon these peripheral intrusions that the estimate of the sufficiency of the porphyries to produce the observed structure was based.

STRUCTURE OF THE RICO DOME.

Elements of the structure.—The structure of the Rico dome has been well exposed by erosion. Directly through its center the Dolores River has cut its course, dividing the mountains into eastern and western groups, which are further dissected by the tributaries of the master stream. From almost any commanding position within the central part of the area the strata may be observed to dip in all directions away from the region about the lower valley of Silver Creek, a fact which is illustrated in several of the photographs and in the distribution of the geological formations as shown on the accompanying map.

Pls. III-VI show the attitude of the strata in accord with the dome structure on the slopes of Dolores, Blackhawk, and Sandstone mountains. The general structure thus exhibited in a large way is found to hold also in detail, and, aside from landslide blocks, there are known but few instances of strata belonging above the Algonkian in which the dip is toward the center. Very locally such dips occur adjacent to the several reversed faults of the region, but these are as a rule unimportant.

Were the whole of the deformation expressed by such quaquaversal dips the structure of the region would be comparatively simple, but this is not the case; the dome is not a simple structure in which the strata have been only flexed and tilted; they have also been faulted, and in such a manner that the dome effect is increased by the displacement of the faults. There appears to be no law or order controlling

the direction of the faults, but to the rule that the upthrow of faults is toward the inside of the dome there are only a few exceptions.

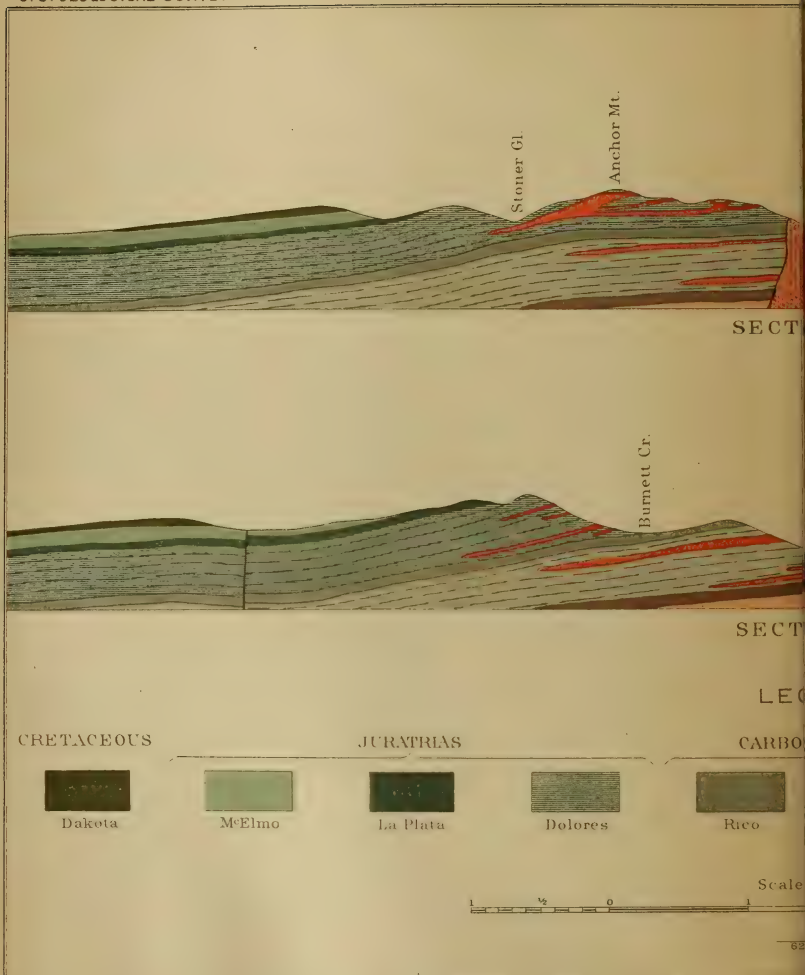
Still another factor in the deformation has been the intrusion of porphyry sheets at various horizons. Concerning these it has been noted in another place that they are more abundant in the upper horizons of the Dolores formation than in any other part of the section, so that their effect has been greater upon the higher horizons now removed from the central portion of the mountains than upon the lower strata which still remain.

The local structure in those parts of the area wherein it is not obscured by surface deposits may be learned from the distribution of the formations as exhibited on the geological map accompanying this report. On this map strike and dip have been indicated by an appropriate sign: the strike by a line drawn in its direction, and the dip by a shorter line at right angles to it, indicating the direction toward which the strata fall, the amount of deviation from the horizontal being indicated in degrees. Aside from this the manner in which the formation lines and sheets cross the contours upon the mountain slopes indicates clearly the general dip of the rocks. Upon the east side of the area the structure is well brought out by the lines bounding the Rico and the upper part of the Hermosa formation, together with the accompanying igneous sheets. Upon the west side these horizons are largely hidden, but the distribution of the porphyries shows the structure, as do also the tongues of the La Plata and McElmo formations upon the main ridges.

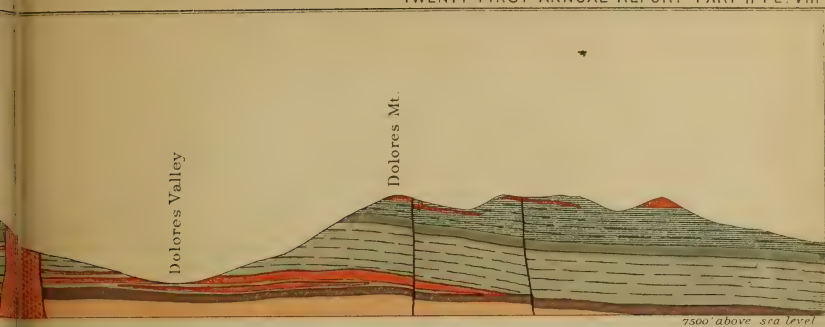
Profile sections.—On Pl. VIII are presented two profile sections through the heart of the Rico Mountains, exhibiting the dome structure. These sections are constructed on the scale 1:62,500, or about 1 inch to the mile—the scale of the Rico and Engineer Mountain atlas sheets—and the vertical equals the horizontal scale.

Section A-A extends from the gently inclined flat-topped ridge west of Eagle Peak, which lies directly west of Calico Peak, in a direction S. 79° E., passing through the saddle near the summit of Anchor Mountain, across the east ridge of Expectation Mountain, through the summit of Dolores Mountain, and across the flat ridge south of Blackhawk Peak. It shows the extent to which the Juratrias and Cretaceous formations of Eagle Peak take part in the structure, and the dome is specially brought out by the band representing the Rico formation. The flat position of the formations in the Dolores Valley is due to the strike being so nearly parallel to the course of the section. This section is located to avoid the larger faults and thus to bring out the amount of domal folding the more clearly.

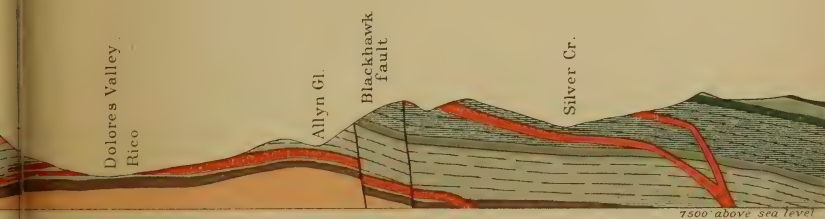
The porphyry sheets of Anchor and Expectation mountains are represented as branches of one body to express the fact shown on the north face of the former summit. It may be that they are distinct on the line of the profile.



PROFILE SECTIONS TH



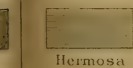
SECTION A-A



SECTION B-B

LEGEND

PROTEROZOUS



DEVONIAN



ALGONKIAN



IGNEOUS ROCKS



Monzonite porphyry



Monzonite

in miles



THROUGH THE RICO DOME

JULIUS BIEN & CO. N.Y.



An arm of the monzonite stock is shown as cutting across the strata on the eastern slope of Expectation Mountain for the reason that a tunnel nearly on the line of section encounters that rock on penetrating the landslide débris of the shoulder projecting into Sulphur Gulch.

Section BB crosses the Dolores River within the town of Rico with a course N. 78° E. On the west it crosses the summit between Storm Peak and Landslip Mountain and ends on the sloping mesa of the Dakota sandstone between Stoner and Priest gulches. To the east it crosses Allyn Gulch and the Blackhawk fault a little above the Maggie Mine, and its eastern end is slightly beyond the unnamed point seen in Pl. I where the La Plata, McElmo, and Dakota formations appear still possessing the dip of the Rico uplift.

In Section BB the appearance of the Dakota on either extreme brings out the lateral extent of the domal structure, and the gradual change to the Plateau country on the west is exhibited.

The porphyry sheets of the Silver Creek region are represented as ascending on the east side of the dome, in harmony with the idea brought out in a preceding chapter that the source of the porphyry magmas on this side of the dome appears to be independent of the center of uplift and situated near its border.

Amount of deformation by folding.—Deformation has been simply defined by Gilbert¹ as “the process by which level strata are transformed into dipping strata.” The result of deformation by folding at Rico has been an essentially domal structure, recognizable by the attitude and distribution of the geological formations. In so far as these are exhibited upon the surface they may also serve as a partial basis for measuring the amount of deformation which has taken place, and by restoring higher horizons, using the known thicknesses given at the beginning of this chapter, a fair estimate may be obtained of the total amount of the local uplift.

The profile sections of Pl. VIII give a basis upon which the amount of the uplift can be approximately realized at a glance, but a more definite conception may be gained by restoring some particular stratum to the position it may be assumed to have occupied before erosion of the uplifted rocks.

The most comprehensive view of the Rico structure is to be obtained from a consideration of the La Plata sandstone. Before the dome was dissected the base of this formation over the summit was at least 4,400 feet above the lowest rocks now exposed at Rico on the line of Section BB of Pl. VIII, and probably somewhat higher, since the above figure is estimated from the thickness of the Hermosa, Rico, and Dolores formations and the Newman Hill porphyry sheet, and takes no account of other probable intrusive sheets. The base of the La Plata on this estimate must have been at about the altitude of 13,200 feet—500 feet

¹ Geologic Atlas U. S., folio 36, Pueblo, Colorado, 1897, p. 4.

or more above the highest peak of the Rico district. It is plain that some of this elevation may be due to faulting, but it will be seen from the map that the uplift by dislocation is mainly north of the line of Section BB.

The amount of local doming which is thus indicated may be seen by comparing the position of the La Plata in the vicinity. About 5 miles north of Rico the base of the formation crosses the Dolores River at an elevation of 9,300 feet, showing a fall from the restored position over Rico of 3,900 feet, or nearly 800 feet per mile, independent of the influence of the porphyry sheet. Beyond this outcrop the northward dips are continued for only a short distance, so that here we have the full measure of the local deformation in this direction. In other directions the fall per mile is less, but the dips are continued for a greater distance. Thus from the northwest around to the south the average deformation or dip slope varies from 400 to 600 feet per mile for a distance of from 5 to 8 miles, beyond which it gradually lessens as the distance from the center increases. The diminished dips continue for many miles toward the west into the Plateau region. Toward the south they fall at the rate of about 500 feet per mile, and are met by the structure of the La Plata Mountains at a distance of about 7 miles. Also to the southeast, though the La Plata is missing, the lower strata fall at the rate of 300 feet per mile for about 8 miles, where the local structure is completely neutralized by the contrary dips away from the Needle Mountains. To the east a distance of 4 miles finds the base of the La Plata 1,700 feet lower than over the top of the dome and dipping to the northeast, in which direction it continues to fall for several miles.

The best basis for estimating the position of the La Plata at Rico before the uplift is obtained by noting its occurrence in nearly horizontal position at 9,300 feet in the Dolores Valley at the mouth of Barlow Creek, 6 miles northeast of Rico, and at 8,500 feet at the mouth of Bear Creek, 12 miles southwest of that town. If the fall in this distance of 18 miles was equally distributed before the uplift, as seems probable, the base of the La Plata at the site of Rico was near the horizon now found at 9,030 feet, limiting the porphyry sheet of Newman Hill, and the domal uplift to the restored position amounts to 3,670 feet.

Uplift due to intrusive porphyries.—The additional deformation due to sheets and laccoliths can not be estimated excepting in a very crude way from the bodies which have escaped erosion. In the central part of the area the Newman Hill porphyry, the influence of which has already been mentioned in the preceding section, has a thickness of 500 feet, proved by the exposures and the drill hole sunk in the Skeptical shaft. Another important sheet near the top of the Hermosa formation has a maximum thickness of 250 feet where it crosses the

river above Montelores, south of the area of the special map, but thins out as it rises with the dome, until it finally disappears entirely in Deadwood Gulch. Its distribution is such that it can hardly be supposed to have been present in the central part of the dome. Other porphyries in this formation, so far as they are exhibited in surface exposures, are of minor importance and could certainly in no single section aggregate more than 200 feet.

The Dolores formation seems to have been, for some reason, especially favorable for receiving sheets and laccolithic intrusions; and these are localized, with respect to the dome, upon the eastern and western sides. The portion of the formation in which they occur does not contain similar intrusions to the north or to the south, where cut by the Dolores Valley. Whether or not there were like intrusions over the central part of the dome can not be determined, but it would seem more likely that they did not exist from the fact that no central cross-cutting bodies of porphyry which could have fed them are known; however this may have been, the porphyries which now remain reach locally an aggregate thickness of perhaps 600 or 700 feet, and by this amount must have augmented the arching of the La Plata and higher formations.

The horizons above the La Plata doubtless suffered still more deformation from injected porphyry bodies, but large masses of igneous rock are at present to be seen only in the cap of Elliott Mountain and in the Flattop laccolith to the northeast, upon the line between the Telluride and Engineer Mountain quadrangles. The former is immediately above the La Plata sandstone, while the latter lies on top of the Dakota and is capped by the shale of the lower Mancos formation.

The mass of monzonite which cuts through the sedimentary rocks upon the west side of the dome has caused a considerable amount of metamorphism in the adjacent rocks, but there is no evidence that the strata have been turned up around its periphery. Its influence in modifying the dome must be compared to that of the block faults near Silver Creek, but there is absolutely no basis for measuring it.

Deformation by faulting.—In the process of uplift or deformation by which the Rico dome was produced the strata were no doubt fissured and fractured to a considerable extent. At the present time a great many old fissures may be detected. Most of them are filled by vein matter, partly ore-bearing, partly barren; and in some cases the evidence is clear that the veins are lines of faulting. The displacement on the faults varies from more than a thousand feet to that which is scarcely measurable.

The supposition that the faults of the Rico Mountains are fractures contemporaneous with the domal folding, merely expressing relief of great tension by rupture of the rocks instead of further bending, seems in itself natural, but is opposed by the considerations connected

with the intrusion of the igneous rocks. From the generally accepted theories in regard to the relations of igneous intrusion of laccolithic character to domal uplift it is necessary to assume that the porphyry sheets of Rico are contemporaneous with or later than the principal uplift. But these igneous bodies are cut by all faults observed to come in contact with them. No single instance was found of a porphyry dike ascending on a fault fissure. Further, the monzonite stock is traversed by many quartz veins, some of them bearing sulphide ores. It is therefore necessary to disconnect the fault phenomena of this region from the primary domal uplift, although it is of course possible, or even probable, that some unidentifiable portion of the folding accompanied the faulting.

In character the faults vary from clean-cut fissures to zones of sheeting or brecciation many feet in width. Extreme brecciation is well shown in various portions of the Blackhawk fault, in the Calumet, Zulu Chief, and several tunnels near Rico, in the "great vein" of the northern part of C. H. C. Hill, and in the boundary zones of the Algonkian quartzites in Silver Creek. Sheeting is seen in most of these localities.

The distribution of the main faults is shown by the map. The greater dislocations are near the center of the dome, but a large number of lesser fractures occur in the circle of peaks about it. A glance at the map will show that there is no pronounced systematic arrangement of the faults. In certain localities the principal fissures may have a common trend, with minor zones intersecting at oblique angles. This is illustrated in the southeast corner of the region, in Silver Gulch, in the Dolores Valley near Burns, and in Newman Hill. As a rule, the faults are nearly vertical, but dip at variably steep angles in some cases.

The displacement of the faults in relation to the dome structure is subject to a simple rule for nearly all of those found at some distance from the center. When even approximately parallel to the strike of the strata the upthrow is on the inside, or toward the center, of the dome. The only important exception to this rule is the great fault of Telescope Mountain, which must be classed with the block faults of Silver Creek.

It is evident that all faults obeying the above rule have served to increase the uplift near the center of the dome. But it must be assumed that most of them lie out gradually as they pass upward, and it may be questioned whether any of the dislocations of less than 300 feet in amount cut through the Mancos shales, assumed to have overlain the Dakota sandstone at the time of uplift. The Blackhawk and Nellie Bly faults are the important ones following this rule, and their effect at the horizon of the La Plata sandstone must have been still measurable by hundreds of feet. But if the lateral extent of these faults be

compared with the diameter of the dome, as represented in the sections of Pl. VIII, it will be realized that the modification of the dome by dislocations following the rule stated above was not great and was confined to the central portion.

The faults bounding the Algonkian schists and quartzites differ from most of the other faults in that they limit small blocks pushed up in the heart of the dome. So far as the fractures are known they are nearly vertical. The amount of upthrust is indeterminable, for no remnants of the Paleozoic sediments lie on the Algonkian blocks. These old rocks then represent plugs punched up through the strata and porphyry sheets without much, if any, visible disturbance of the adjoining beds at the horizons seen. These blocks are comparable to the monzonite stock in this respect, but from their small size the disturbance in the dome structure above them must have been much less than that above the stock, assuming that the stock magma did not reach the surface. These fault blocks may perhaps be regarded as quite analogous to the stock eruption, in that both seem to be comparatively recent manifestations of an upward force suddenly exerted, producing vertical fissures rather than folding. If the fault blocks represented by the Algonkian rocks of existing exposures extended upward for some distance with nearly vertical walls their disturbance of the dome structure may have reached to the upper shale series of the Cretaceous, but if they wedged out upward the faulting must have been resolved into local tilting of adjacent beds.

The great fault of Telescope Mountain is so undetermined as to its course and its relations to various other possible fissures that little need be said here as to its effect upon the Rico dome. If a single fault, it must have materially modified the symmetry of the dome at the horizon of the La Plata sandstone.

BEDDING FAULTS.¹

The term "bedding fault" is here applied to dislocations which follow planes of stratification.² Dislocations of this kind are to be observed in several of the mines of the Rico district, particularly in the mines of C. H. C. Hill and those of Newman Hill. In both places they have been the locus of ore deposition, and in the latter have afforded a great deal of ore, which, if not so abundant as that occurring in the verticals, has usually been much richer. The veins and ore deposits of Newman Hill have been studied in detail by John B. Farish and T. A. Rickard,

¹ The section on Bedding Faults is by A. C. Spencer. Since the report upon the Rico ore deposits can not accompany the discussion of the geology, as was intended, it seems desirable to refer somewhat fully to the geological features of the peculiar ore bodies of Newman Hill, which are intimately connected with bedding faults. A full discussion must be deferred.—W. C.

² Upon the subject of bedding faults see descriptions of the silver and contact faults, by J. E. Spurr, in *Geology of the Aspen Mining District, Colorado*: Mon. U. S. Geol. Survey, Vol. XXXI, pp. 82, 113.

who have at different times superintended the operation of the Enterprise mine, and in the papers which they have written many valuable observations and conclusions regarding the geological relations exhibited by the ores have been recorded. In both of these papers the geology of the "contact" deposits of Newman Hill is discussed at length.¹

The term "contact" is used at Rico in an indefinite and incorrect sense, and has also been misapplied by Farish and Rickard. In the local usage the word is not applied in its legitimate sense to the plane of contact between different rock masses, but rather to any ore-bearing horizon or zone even approximately parallel to stratification. In Newman Hill it is applied to a brecciated ore-bearing zone which is not necessarily between the same formations throughout its course.

Quotation from Farish.—An accurate conception of the bedding fault and of the so-called "contact" can not be better conveyed than by quoting from the above-mentioned papers. Mr. Farish says:

Attention has been called to a band of limestone that occurs midway in the series of alternating shales and sandstone strata. It is a grayish deposit, varying in thickness from 18 to 30 inches, and occupies throughout Newman Hill the same stratigraphical position with reference to the other beds. From its close relation to the ore deposits, this band is locally known as the "contact limestone." It is inclosed between two layers of argillaceous shale, which are, however, quite different in appearance. The overlying stratum is a soft, comminuted, drab-colored shale, varying in thickness from 6 to 20 feet. This layer forms an impervious shed to the surface waters circulating about it, thus leaving the mine workings below comparatively dry. The underlying bed is a black, finely laminated shale from 7 to 12 feet in thickness, which rests upon the series of alternating gray sandstones and drab and greenish shales.

Description of the "contact" by Rickard.—The description by Mr. Rickard² is more detailed, and is quoted, in part indirectly, as follows:

The accounts which have been given³ of a "contact limestone," overlain by a "drab shale" and underlain by a "finely laminated shale," may describe certain sections of this ore-bearing horizon, but they do not characterize it as a whole, and they give a misleading idea of its real nature.

In four parts of the Enterprise mine the contact is found respectively in a crystalline lime, overlain by black shale and underlain by sandstone; in a lime breccia, overlain by sandstone and underlain by a gray limestone; in a mass of crushed quartzose lime, covered by black shale and overlying a blocky limestone; and at the base of a bed of gypsum having a maximum thickness of 15 feet, with limestone below it.⁴

The ore of the contact can not be said to be confined to any particular encasement, but one may venture the generalization that it is to be sought for in a layer of crushed

¹ On the ore deposits of Newman Hill, near Rico, Colorado, by John B. Farish: Proc. Colorado Sci. Soc., Vol. IV, pp. 151-161.

² The Enterprise mine, Rico, Colorado, by T. A. Rickard: Trans. Am. Inst. Min. Eng. for 1896, Vol. XXVI, 1897, pp. 966-989.

³ Loc. cit., pp. 966-970 and 976.

⁴ Referring to Farish's description just quoted.

⁵ In the Rico-Aspen mine the limestone which occurs beneath the gypsum is blocky in its fracture, like that occurring below the contact in the Enterprise workings.—A. C. S.

rock which occurs along a certain horizon marked by a thinly bedded series of black limestones and shales. The parts of the contact explored during my period of management were very frequently characterized by a distinct breccia made up principally, but not solely, of lime fragments. Pieces of shale and sandstone were recognizable as derived from adjacent beds, and fragments of porphyrite were traceable to neighboring intrusions of that rock. The contact above the Jumbo No. 2¹ frequently consisted of compact pulverulent lime, graduating into breccia overhead and underlain by blocky lime; that above the Enterprise¹ was often breccia, shading off into blocky lime overhead and underlain by black shale, while the ore of the Jumbo No. 3¹ contact was found between a powdery brown lime and a thin bed of black shale. The variability of the stratigraphical position of the ore thus emphasized is due to the nonpersistence of individual beds. The pulverulent lime indicates crushing, probably connected with an invasion of porphyrite above it.

The wavy compact texture of the gypsum suggests an origin by a sulphatization of lime breccia through the agency of solutions coming from neighboring ore-bearing measures.

The contact zone has been the victim of all disturbances tending to deform the rocks. A thickness of closely laminated shales is laid upon blocky limestones and sandstones. To the formation of a fracture the latter rocks would offer no particular obstacle, because of their homogeneity, but the upward extension of a fracture would be impeded, if not stopped, by meeting a series of beds which, on account of their laminated structure, are easy to bend, but hard to break. There is nothing fanciful in this reasoning. Thus, it seems to me, the structure of the rocks of the horizon now known as the "contact" was the immediate cause of the repeated shattering which that horizon underwent. It was the factor which stopped the upward extension of the vein fractures and produced the consequent limitation to the circulation of those mineral solutions which were the immediate agents of ore deposition. Thus is explained the concentration of large masses of ore along this zone, because it became a dam, checking the circulation in an upward direction. The fractures now followed by the pay veins were unable to break through the shales above the contact, and though the later cross veins were stronger, they too were stopped by the elasticity of these closely laminated beds. In each case, therefore, the force of vertical fracturing was diverted into a horizontal displacement, which soon made the zone under the shales a mass of shattered rock, peculiarly adapted to become the place of ore deposition.

Comment upon the quotations.—These two descriptions are practically in accord, though the first is, as suggested by Mr. Rickard, somewhat misleading because incomplete. Both agree in assigning the fractured and brecciated zone in which the contact and its ores occur to a definite and limited series of strata at a constant horizon. The fact is very clearly expressed by Mr. Rickard that differences in the inclosing rock are due to the original local variations in the strata rather than to the crosscutting of the fractured zone from one horizon to another. That this is the actual state of affairs throughout the mines of Newman Hill is corroborated by the observations of the writers. The sections of the contact and subjacent beds given in the description of the Hermosa formation (pp. 48-59) show the general character of the zone. The marly limestone and blocky limestone just below it were recognized as lithologically identical wherever the contact was visited, and while other

¹ Names of vertical NE. and SW. veins in the Enterprise mine.

beds might come and go these were more constant. So distinct is the marly or pulverulent limestone from any other stratum in the section that little hesitation is felt in suggesting that a similar rock which has been exposed in the Sambo and Lake View tunnels, upon the hillside south of Horse Creek, is representative of the same horizon. However this may be, the "contact" of Newman Hill is believed to be a continuous and individual stratum within the region thus far explored. It is hardly exact to consider the nonpersistence of strata above or below the contact as changing the stratigraphic position of that horizon, as Mr. Rickard has done. Stratigraphic identity may be more certainly recognized by tracing a given rock layer horizontally, even though its character changes from place to place, than by attempting to define it by its occurrence between like strata.

The discussion of the origin of the brecciated zone of Newman Hill by Mr. Rickard can be indorsed in the main. From the relative amount of faulting upon the vertical fissures at depth and in the vicinity of the contact it is evident that the shales have taken up the strain which resulted below in sharp displacement to the measured amount of often 25 feet or more, by flexing and slipping one layer upon another and by brecciation. The inference is not, however, warranted that fissures were not produced in the overlying strata; if faults may die out upward, they may also increase upward with a change of flexibility in the strata, so that it is entirely probable that many of the fissures which are known to be prominent below the contact reappear above, though they may never have been mineralized to the same extent. Evidence tending in this direction may be seen in the faults and fissures in the cliffs back of Newman Hill, where the massive limestones are very much broken up. These may have no correspondence, break for break, with faults occurring at depths, but they are presumably related in origin to the veins of Newman Hill, since they have corresponding courses.

Origin of the bedding faults.—It is possible that the bedding faults at Rico had their origin before the period of faulting, at the time when the upward doming was initiated. If the beds were bent upward, there would naturally be slipping of one stratum upon another, and bedding faults would result. Such an explanation is given by Spurr, as cited above, for brecciated zones and planes of dislocation along the stratification in the Aspen mining region of central Colorado.

In the case of most of the bedding faults at Rico there is no way of ascertaining whether or not this origin is applicable, but in that of the "Newman contact" it is certain that, while the primary break may have been due to tension arising from the flexing of the strata by a gentle uplift, a greater part of the movement and brecciation has resulted from deflection of movement along fissures crossing the stratification.

The origin of the "contact" zone of Newman Hill by the slipping of the beds on each other during uplift, or by the resolution of movement across the bedding into movement parallel to it, may seem sufficient to account for the phenomena observed, and certainly in the several noted cases of bedding faults at other horizons no additional explanation is required, but certain further suggestions may still be made to account in part for the phenomena of Newman Hill.

A secondary origin is suggested by Mr. Rickard for the gypsum which occurs locally above the contact in the mines of Newman Hill, but the facts already stated (p. 53) are believed to be sufficient to prove that the gypsum was really formed in a sedimentary way as an original chemical precipitate. Wherever it occurs it lies immediately above the pulverulent limestone of the "contact," or, as stated by Mr. P. S. Rider, the present superintendent of the Enterprise mine, the gypsum locally occupies the place of the "contact."

In the light of the soluble nature of rock gypsum and the evidence in the Rico-Aspen mine that it has been very much corroded by circulating waters, and also because of the variable thickness of the gypsum bed, it seems possible that the observed relation of the "contact" and the gypsum may be significant of the origin of the former, and connected with the brecciation of the black shales which are found above it. It may be suggested that the gypsum originally occurred over the whole region where the pulverulent marl, which now makes up the "contact," is found, and that the latter is the insoluble residual left after the former was removed by the action of percolating waters. Because of the irregularities which would result from the characteristic corrosion of gypsum, its removal and the consequent sinking of the superjacent strata might well result in a brecciation of the beds originally resting upon such a stratum of gypsum as is supposed to have existed at Rico. The brecciation observed in the mines of Newman Hill may well have originated in this way; especially since it is mainly confined to the black shales which occur above the supposed residuum of the gypsum. The "contact" zone itself is sometimes brecciated and sometimes not, but the strata below it, though consisting of flexible shales and brittle limestones in alternation, are not known to be brecciated at any place. In the breccia, fragments of porphyry derived from a thin sheet lying above it are frequently mixed with the pieces of shale to a distance of several feet below the base of the igneous rock, a feature which would naturally occur under the supposed conditions, but which could also occur if the brecciation were due primarily to a differential movement in the rocks. The localization of the brecciated zone between a certain thin limestone band below the "contact" and the supposed massive sandstones or porphyry above would seem anomalous, if the bedding fault is due primarily to the deforming forces, since the black shales which occur beneath the

"contact"¹ are similar to those above and rest upon a great series of massive beds, above which movement would have been as likely to have occurred as at the horizon observed. It would seem even more natural if there had been a distribution of such a primary movement through the whole thickness of the black shale series. Evidence of such movement might also be expected to occur at many horizons in the section involved.

In view of these considerations, it is thought that there is a fair degree of probability for the truth of the hypothesis proposed. It does not interfere at all with the conclusions of Mr. Rickard that the dynamic forces have been dissipated by bending and by shearing parallel to the strata, since such a brecciated zone would, if existing previous to the deformation, particularly lend itself to further horizontal movement; while, if later than the deformation, it would not affect the problem one way or the other.

ORIGIN OF THE DOME.

From the foregoing discussion it appears that the structure of the Rico Mountains is in many respects similar to that of the La Plata Mountains, and in less degree to that of the Henry Mountains and of other laccolithic groups of the plateau country. The intrusive porphyries are of the type common in all these groups, and their intrusion may be plausibly assumed as nearly contemporaneous in all cases. But while the Henry Mountains are described by Gilbert as entirely due to the intrusion of the porphyry masses, it is clear that in the Rico Mountains the bodies of porphyry, either visible or reasonably to be hypothesized, can not be assumed to have caused the domal uplift as a whole, both on account of their small mass and on account of their position in the dome. Further, the existence of profound faults later than the porphyries shows the action at this center of a powerful vertical upthrust which is not demonstrably connected with igneous intrusion.

The porphyry sheets in the Rico dome must have produced a displacement of overlying strata equal to their mass, and this was certainly an important element in the upper parts of the dome. So far the uplift is due to the intrusion of igneous magmas, and the Rico Mountains are a laccolithic group. The greater part of the uplift which has taken place has affected the whole Paleozoic section and the Algonkian rocks upon which they lie, and thus the small Rico dome comes to show close relationship with the much broader San Juan uplift. As has been stated in an earlier section, the most prominent structure in the San Juan region is pre-Tertiary in origin, but there was also uplift in Tertiary time, and it is possible that the Rico dome is

¹ The sandstones are nowhere exposed, but are stated by Mr. Rickard to lie above the "contact."

synchronous with the later elevation and a result of the same force. The same is true of the La Plata Mountains. But until the structural history of the San Juan region has been studied in much greater detail the relation between the local uplift of the Rico and La Plata mountains and the more nearly continental movements of the San Juan region can not be thoroughly discussed. The developments of the investigation of the Rico Mountains make it very desirable to reexamine the so-called laccolithic groups of the plateau country, for in no case, with the exception of the Henry Mountains, has the previous work in those groups been sufficient to demonstrate their character. They may be similar to the Rico and La Plata groups, the igneous intrusions accounting for but a portion of the total uplift. For the La Sal Mountains the probability of such a complex origin has already been pointed out.¹

In discussing the nature of the forces which have produced the Rico uplift, it is apparent that there is a close analogy between the two phases of intrusive action and two phases of structural uplift. The primary upward pressure at this center was one to which the whole section of Paleozoic and Mesozoic strata accommodated itself by folding, stretching, and no doubt by minor fissuring. It would appear to have been a gradually exerted pressure, of the kind generally assumed to have forced the magmas of laccoliths and analogous sheets between the strata of a sedimentary complex. Corresponding to this idea it is found that the distinct porphyry sheets of the Rico Mountains are the earliest intrusions.

The fault blocks of the heart of the mountains, made up of Algonkian schists and quartzites, have been thrust up through the folded strata with little or no evidence of contemporaneous folding of the adjoining beds. This is also the relation of the Darling Ridge monzonite stock, as far as can be seen, and also of the similar stocks of the La Plata, Telluride, and other neighboring quadrangles. Such fault blocks and such masses of igneous rocks seem alike due to forces suddenly exerted, producing vertical fracture instead of doming. With such an analogy before one, there naturally arises the suggestion that a mass of magma forming a stock in greater depth may have followed the upthrust blocks now revealed. Such an hypothesis requires the assumption of very direct connection between the propelling forces of magmas and those of continental uplift. But whatever ultimate connection there may be between these forces, there is good reason to question the theory that structural elevation and the igneous intrusions at Rico are but different phases of one dynamic force.

If it be contended that but one great force has been exerted, it is difficult to explain why larger amounts of magma were not intruded into the

¹ Laccolithic mountain groups, etc.

strata of the Rico dome, in view of the large igneous masses of probably contemporaneous origin occurring near at hand in comparatively undisturbed beds. A single mass of porphyry, exceeding in bulk all the sheets of the Rico Mountains put together, occurs just at the northeast base of the dome, and similar large bodies occur on the San Miguel River in the Telluride quadrangle. The stocks of the Telluride quadrangle appear likewise to be distributed without visible relation to any structure of the sedimentary formations. In other words, it appears to be the case that both laccolithic and stock eruptions of this region may be independent of centers of structural movements of the crust. Intrusions have occurred at points of structural weakness, but have also taken place in much greater volume at points variously related to such centers. With this brief reference to the problem of the origin of the Rico dome, its further discussion is postponed until the investigation of the San Juan region and of the mountain groups of the plateau country has furnished much needed data.

DESCRIPTION OF THE FAULTS.

Spruce Gulch fault. This fault runs along the northeast bank, not far from the creek bed, with a general course about N. 50° W., and is nearly vertical. It is more plainly seen a little beyond the southern boundary of the area mapped, where the Montelores porphyry sheet is dislocated. The line of the break can be closely determined here, and the amount of upthrow is estimated at nearly 400 feet upon the northeast. The fault is not accurately determinable in the lower part of the gulch, being concealed by wash or broken-up landslide material of an area shown on the map. If the lower porphyry sheet, which is known in the creek bed, exists on the northeast of the fault, it was not detected and has been omitted from the map, since it is very possible that it thins out rapidly to the eastward. Outcrops do not exist by which the northwestern extension of this fault may be recognized. It is thought that a tunnel at an elevation of about 8,725 feet on the north side of Spruce Gulch and running nearly east intersects this fault, but as the workings were caved in at the time of visit no definite evidence was obtained. The course of the fault would carry it into the landslide area south of Sulphur Gulch and in the direction of Expectation Mountain.

Deadwood fault. This fault crosses Deadwood Gulch at about 9,150 feet, being hidden upon the north side by the débris which covers Newman Hill. On the south side of the creek it may be located accurately and its displacement estimated from the position on either side of it of the limestone strata belonging to the middle part of the Hermosa formation. The faulting of the massive limestones is apparent in looking across Deadwood Creek from the edge of Newman Hill.

The dislocation is up on the north, and amounts to approximately 250 feet in the cliffs south of the gulch, but diminishes toward the east. Its course, where it crosses the creek, is between N. 65° W. and N. 70° W. Upon its north side the strike of the strata is N. 40° W. and the dip 37° SW., while to the south of the break the strike is N. 70° W. and the dip 4° SW.

The economic importance of this fault lies in the fact that it displaces the ore-bearing horizon of Newman Hill. There is little room to doubt that the black shale and the shale breccia which are exposed in the Stephanite tunnel at the mouth of Deadwood Gulch represent the black shale series of the "contact," and are continuous northward to the workings of the Rico-Aspen mine. These black shales are found about 100 feet from the mouth of the adit, which had penetrated surface gravels to near this point. The strike of the Deadwood fault would carry it across the Stephanite tunnel, but the occurrence of the black shale at the point mentioned indicates that the line of the fault must be somewhat farther south than the exposures of shale, and that its course is intersected by the tunnel in the gravel area.

If it were desired to reach the horizon of the "contact" immediately south of the fault it would be necessary to sink at least 250 feet, and to a greater depth as the distance from the fault increased, because of the southerly dips of the strata. From present evidence there is no reason for supposing that the "contact" would be mineralized south of the fault, for it is not so enriched in the neighborhood of the fault in the Stephanite workings.

Faults of Dolores Mountain and vicinity.—In the area between the Blackhawk and Deadwood faults, and extending to the corner of the area mapped, there are several faults of minor importance. These seem to fall into two systems: The faults of the most prominent system have courses between N. 45° W. and N. 60° W.; those of the second system vary between nearly north-south and N. 20° W. The main fissures are nearly parallel in their general trend to both the Blackhawk and the Deadwood faults. In amount of throw they range from a few feet up to about 400 feet, though they are mostly under 150 feet. The maximum is reached in two compensating faults to be found upon the north side of Dolores Mountain. These breaks may be assigned one to each of the two systems, and they consequently intersect, as represented on the map. Between them a wedge-shaped mass has been dropped. The relations of the eastern fault are very obscure throughout, and this is also true of the lower part of the western break, but the latter is well shown at the head of the ravine, where it displaces the thick porphyry mass which forms the cap of Dolores Mountain. Upon the south side of the ridge the rocks are very poorly exposed, and the amount of the fault is not definitely

determinable. The thin sheets of porphyry which are represented on the map may not be all that are actually present in this region, and those that have been located do not afford a clue as to the amount of displacement. To the east of this fault the main porphyry sheet must thin out rapidly southward, as the one found at its horizon on the southern slopes is less than 50 feet in thickness.

Certain of the faults in this region are contrary to the rule of upthrow on the inside of the dome, but these are unimportant.

Blackhawk fault.—The Blackhawk fault is so called from the mine located upon it where it has the maximum displacement. It has been traced from the divide between Allyn Gulch and the northern headwaters of Scotch Creek, south of Blackhawk Peak, to the ridge above Nigger Baby Hill. It seems to correspond to the vein of the Pigeon mine upon C. H. C. Hill, and is probably also identical with either the A. B. G. or the C. V. G. vein at Burns; or, what is more likely, these fault fissures represent a splitting of the Blackhawk fault. Accepting this as correct, the fault is known for a distance of more than 4 miles. Its general course is about N. 52° W., though there are many local deviations from this direction. The throw is always up upon the southwest side.

Rarely is the fault well exposed at the surface, and the throw being extremely variable it is difficult to obtain accurate measurement of the displacement. At Burns the A. B. G. fissure shows a fault of about 50 feet, while the amount upon the C. V. G. could not be estimated, but can not be very large. In the lower part of Uncle Ned draw, opposite the Blackhawk mine, the throw is 85 or 90 feet, as measured by the displacement of the Fusulina layer and the base of the Rico formation. These are the only places where it was actually measured, and in both cases the fault is upon a single plane. Upon C. H. C. Hill it is not exposed at the surface, but under ground is found to be a brecciated vein, which has a width of 50 feet in the Don Cameron tunnel.

From the bed of Silver Creek southward the dislocation of the Blackhawk fault is very greatly increased. As will be explained more at length in describing the Nellie Bly and Last Chance faults, it is assumed that a large part of the dislocation on those fractures has been taken up by the Blackhawk fault south of the points of intersection, thus accounting for the great variation in throw upon the latter. Unfortunately the area within which the relations of these faults must be determined is entirely covered by surface wash, and the existing mine workings were either inaccessible when this investigation was in progress or are so situated as to throw little light upon the subject.

It is supposed that the Nellie Bly fault crosses the Blackhawk very near the Argentine shaft, in Silver Creek. At the time of visit this shaft was full of water, but from the best obtainable information the

exploration from it was entirely upon the Blackhawk vein. Similarly the old workings of the Blackhawk mine, while extensive, were prosecuted without appreciation of the fact that the vein represented a fault fissure and were directed to exploration of the ore shoots dipping away from the main vein, or of the branch veins, such as the Maggie, also located on the eastern side. There is thus little or no development west of the Blackhawk vein where the Last Chance fault would meet it if continued across the covered area east of Allyn Gulch with the strike observed to the westward.

The maze of workings in the Blackhawk mine have thus far defied any simple interpretation of the structural relations of the ore bodies at this point; but it is plain that the shoots of sulphide ores dipping steeply away from the main vein represent replacement deposits in the massive limestones of the Hermosa, the upper beds of which can be seen in the lower cliffs east of the vein, and the magnitude of the Blackhawk fault at this point is shown by the altitude at which these same limestones meet the fault in their descent from the north slopes of Dolores Mountain. As shown by the map, they are cut off by the fault on the northeast side of Allyn Gulch at a considerable distance from the lower workings of the Blackhawk. As the dips are steep to the east of the fault and several minor faults occur between these two points, the statement of the amount of faulting of the limestones can be only a general one. It is between 600 and 800 feet in the aggregate, and most of it belongs undoubtedly to the Blackhawk fault.

The dislocation has taken place upon a fissure zone for a part, if not the whole, of the distance between the lower Blackhawk workings and the west slope of Blackhawk Peak. Whether the two fissures continue separate for the entire length mentioned or unite in the upper part of Allyn Gulch is not known, for surface *débris* conceals the vein from a point near the Maggie shaft to the cliffs of Blackhawk Peak, and the meager evidence of a few prospects is not conclusive. The branching of the vein at the north is very clearly shown on the surface, and the wedge of rock between fissures is seen to be crushed, traversed by many small quartz veins, greatly impregnated by pyrite, and thoroughly decomposed. A small porphyry dike is seen in this area. On the trail crossing this fracture at about 10,350 feet the calcareous beds have been much metamorphosed, with production of garnet and other unidentified silicates, while scales of specular iron are abundant. Such metamorphism is elsewhere in these mountains restricted to the contact zone of the monzonite stock.

The Blackhawk fault is nearly vertical in the main, but has somewhat undulating walls. At the head of Allyn Gulch, where crossed by the ravines heading north of Blackhawk Peak, a tunnel on the fault vein exhibits a series of fractures between which the rock is crushed

and sheeted. Several walls dip northeasterly at angles between 45° and 65° , but the fissure zone as a whole is much more nearly vertical. Between the outer fissures in the cliffs toward Blackhawk Peak is a porphyry mass, much crushed, which is interpreted as belonging to the large sheet seen on either side.

At the time the Blackhawk fault was being studied it was supposed that the mineralized fractures which are to be seen in the Alleghany, Maggie, and Privateer veins were offshoots from the Blackhawk fissure, but the presence of the several important nearly east-west faults of Silver Creek has since been ascertained, so that it seems more probable that these veins are the reduced eastward equivalents of the profound faults of Silver Creek. In the case of the Nellie Bly fault the identity may be considered as well established upon both sides of the Blackhawk fissure. Upon the east side its throw is not more than 150 feet, while upon the west it is much greater.

Nellie Bly fault.—The claim from which the name for this fault has been derived is a relocation of ground which was taken up under the name of Alma Mater, but which was never patented. The fissure is a fault which was first recognized upon the surface on the slope above the Iron mine on the north side of Silver Creek. At this place the strata upon the north belong to the upper part of the Hermosa formation and dip gently into the hill (strike N. 80° E.; dip 10° to the west of north), while to the south of the break occur the massive limestones belonging to the middle part of the Hermosa, with a strike N. 80° W. and dip 30° to the east of north. The course of the break here is N. 80° W., but this changes toward the west to N. 85° W., and finally to nearly east-west. The outcrop of the fault rises diagonally across Nigger Baby Hill and the fissure is cut in the Eureka tunnel at the mouth, in the new or upper Nellie Bly tunnel at 20 feet from daylight, and in the upper Alma Mater tunnel at a distance of about 75 feet from the entrance. It also passes through the incline of the old Grand View mine on the crest of the hill and may be recognized upon the western slope in a tunnel at 9,830 feet. It is this fault which has dropped the ore bodies in the Iron mine down upon the north side.

In the various places where it was seen the attitude of the fault varied from nearly vertical to an inclination of 45° toward the north. The amount of displacement back of the Iron mine must be at least 250 feet, and the tilting of the block to the south of the break causes a rapid increase in displacement toward the west. The amount of the throw at the Grand View incline is estimated at 750 feet. The fault is clean cut wherever observed, and examination of the break shows so little evidence of crushing that it is difficult to believe that the known amount of displacement could have taken place along this fissure. The magnitude of the fault is very plainly shown near the Nellie Bly tunnel, outcrops of the massive limestone of the middle

portion of the Hermosa occurring on the lower side of the fault within a few yards of the Fusulina layer at the top of that formation, on the upper side.

In the lower part of Nigger Baby Hill upon the west side the Nellie Bly fault is completely hidden by surface wash. Its course would carry it under the alluvial fan at the mouth of Aztec Gulch and in the general direction of the Aztec vein, which crosses the gulch at 9,400 feet, with a course approximately N. 75° W. There is thus strong probability that the Nellie Bly and Aztec veins are identical, and that there is profound faulting upon the west side of the river as well as upon the east. The amount of mineralization in Aztec Gulch is in excess of that observed on Nigger Baby Hill as regards this fissure. There is strong probability, also, that some one of the heavy quartz veins, having a nearly east-west course, in the north fork of Iron Gulch is identical with the Aztec vein. The Zulu Chief tunnel, for instance, cuts two brecciated zones, one near its mouth and another about 200 feet from its entrance. Both are accompanied by quartz veins, and the former may correspond with the Aztec vein. Unfortunately it is not possible to determine the distribution of rock in place in all this region, so that the amount of possible faulting can not be estimated.

Eastward from the ravine back of the Iron mine the fault is obscured as far as the Black Hawk fault, but east of that fissure a fault, supposed to be the extension of the Nellie Bly, appears, and, gradually swinging toward the southeast, throws the base of the Rico formation down upon the north to the amount of 150 feet. Still continuing eastward, it may be traced up Honduras Draw and across the ridge at its head, where it is covered by the talus and slide rock in the adjoining basin, and beyond that point dies out as a distinct fault.

Last Chance fault.—The Last Chance fault takes its name from a prospect located upon it where it crosses the main trail on the south side of Nigger Baby Hill at the elevation of 9,350 feet. This fault, like the last, is important, and, having a course from N. 80° W. to N. 85° W., is nearly parallel to it. The distance between the two is from 700 to 900 feet in the region where both have been located. The apex of the fault runs diagonally athwart the southern slope of Nigger Baby Hill, rising toward the west. Its last appearance before passing under the surface wash is in the Amazon workings at 9,400 feet, on the Nigger Baby trail. Still farther west, however, near the base of the hill, there are three well-marked fissures in the same general course, and about 100 feet apart. These seem to represent a forking of the Last Chance fault.

If the designation of the quartzites south of the Last Chance fault in Silver Creek as Algonkian is correct, the amount of upthrust along the break in this region is upward of 1,000 feet. On the southern of

the three fissures to the west there is a minimum displacement of 600 feet if the quartzites have been correctly assigned to the Devonian, while 400 feet may be attributed to the next. There are no data for determining the amount of displacement upon the third. The Nora-Lily tunnel is upon the central of these three fissures, with the Devonian quartzite upon one wall and the lower shale of the Hermosa upon the other.

These three fissures probably cross the river and reappear in the vicinity of the Lucky Pine or Calumet tunnel, which is probably upon the northernmost break. At this place there is a great deal of brecciation, perhaps due to a reunion of the fissures, the products of alteration occupying a zone fully 50 feet in width. As in the case of the Nellie Bly fissure, these may have their representatives in some of the imperfectly explored quartz veins which cross the ridge at the head of Aztec Gulch.

If, as suggested in the discussion of the relations of the fissures east of the Blackhawk fault, these are the eastward continuation of the faults of Silver Creek, it may well be that the Leila Davis, Alleghany, and Maggie veins correspond to the Last Chance fault, the great displacement of strata having been taken up in part by the Blackhawk break, but having died out to some extent before reaching it.

The extension of the Last Chance fault to intersection with the Blackhawk seems the most plausible way to account for the greatly increased dislocation on the latter south of Silver Creek; and if the fractures bounding the Algonkian quartzites are later than the majority of the faults of the region, it might well be that the Blackhawk fault was already in existence, with a throw like that seen north of Silver Creek, at the time the Last Chance fissure was formed, and would thus naturally prove a line of weakness to which the major part of the new dislocation might be deflected.

Smelter fault.—A fault of considerable local importance is shown on the map crossing the lower slope of Nigger Baby Hill in a direction N. 82°–84° E. This course carries it under the Grand View smelter, whence the name here given to it. The fault has not been observed in any distinct surface outcrops, but its position is evident to within a very few feet, where the Devonian limestone comes close to the Algonkian schists above the smelter and a little higher, on the railroad switchback, where the lowest Hermosa strata are seen almost abutting against the schists, which are also exposed at the Futurity tunnel nearly 150 feet still farther up the slope. South of the Smelter fault, from the Devonian line to the Fate shaft, in Silver Creek, there are many exposures of the lower Hermosa sandstones and shales with strikes varying from east-west to N. 80° E. and with dips of between 30° and 40° southerly, carrying them under the porphyry sheet shown on the map.

The eastward projection of the Smelter fault carries it where a fault seems necessary on the south side of the Algonkian quartzites, which are exposed on the slope between the old Phoenix tramhouse and the Last Chance tunnel. If continued it would intercept the Last Chance fault near the mouth of Allyn Gulch.

To the westward the Smelter fault would, if projected in a straight line, cross the Dolores and strike into the covered slope northeast of Iron Gulch, crossing the South Park fault about at the smelter. There is a possibility, as mentioned below, that a fracture connected with the Smelter fault does extend across the river in a direction south of west, but it seems certain that the main dislocation on the Smelter fault turns to the northwest at some point near the smelter and forms the southwestern boundary of the schist area above Piedmont. It may be that the deflection to this course was caused by a pre-existing fissure—such as the South Park fault may be—but in any case the fault limiting the schists must be considered as in effect a part of the Smelter fault.

The narrow band between the monzonite and the schists is very poorly exposed, but the Montezuma and other tunnels show that there is here a broad band of brecciated quartzite—a fault zone. Its general course is parallel to the fault line of the map. The quartzites are so brecciated that their structure can not be made out at any point seen, but they are in the normal position for Devonian quartzite, and are so colored on the map. If the structure is simple here the limestone of the Devonian must be cut by the monzonite, but outcrops of the contact were not found. The upper extremity of the schists is covered by gravel and slide rock, so that the union of the Smelter and Last Chance faults is entirely concealed. Broken lines across the slide area indicate the probable place of junction.

The evidence that a fissure does exist on the northwest side of Iron Gulch, approximately in the course of the Smelter fault as it crosses the base of Nigger Baby Hill, is somewhat peculiar, and may be appropriately given in this place. The map shows a prospect at 9,375 feet a short distance from the gulch. On the slope directly above this prospect, at about 9,500 feet, a funnel-shaped sink in the surface soil and wash leads down to an open crevice in solid rock at about 12 feet from the surface. The crevice runs approximately east and west, has nearly vertical undulating walls, and is 2 to 3 feet wide where seen. A stone dropped into the fissure can be heard striking alternate walls after it passes out of sight and it is believed the fissure must be open to a depth of at least 75 to 100 feet. No ore has been taken from the workings below, which are entirely in monzonite and are caved in, so that the crevice must apparently represent a landslide fracture or an open channel in a vein. Landslide phenomena are not notable on this slope of Darling Ridge.

The dislocation on the Smelter fault below the Futurity tunnel is clearly several hundred feet, but can not be closely estimated because

the upper limit of the schist block—that is to say, the level at which the schists were overlain by the eroded Devonian quartzites—is not indicated by any known evidence. At other points upon its course the throw of the Smelter fault is still more problematical, as will appear in the next section.

Cross faults between Smelter and Last Chance faults.—The wedge-shaped area between these fractures is represented on the map as crossed by two hypothetical faults. Without reference to these this wedge is plainly a narrow block which has been thrust up several hundred or 1,000 feet, nearly in the center of the Rico dome. This band is so long, measuring from the schists west of the river to the Blackhawk tramhouse, that it does not seem reasonable to suppose that it could be thrust up in this manner without many cross fractures, and the rocks exposed in the area also indicate that transverse faulting has occurred.

The western end of this block consists mainly of the Algonkian schists. They are known to extend as far east as the Futurity tunnel, which penetrates them for about 100 feet. Above the tunnel there are no further exposures for some distance. But at the Falcon tunnel, now inaccessible, the mouth of which is located on the fault line where it crosses the 9,250-foot contour, a great deal of common monzonite-porphry was encountered. The course of the tunnel is into the hill, almost north, and the porphyry apparently outcrops at its mouth. A vein and some ore was found at this place some years ago, but at the time of visit no definite information could be obtained as to the workings. Porphyry débris covers the slope above the Falcon tunnel in great abundance, and is also present as partially covered talus eastward beyond the turn in the trail at 9,275 feet. It does not seem likely that all this porphyry débris can come from the mass above the Last Chance fault, and it therefore seems probable that a considerable porphyry body occurs between the Smelter and Last Chance faults from the end of the schists, somewhat above the Futurity eastward to the Algonkian quartzites. Hypothetical cross faults have therefore been represented on the map separating this supposed porphyry area from the schists and quartzites, respectively. It is not certain that porphyry is the only rock in this subordinate block, nor are the courses of the cross faults definitely indicated by evidence.

The quartzite of the eastern part of this block is cut by several veins, which may be faults of some importance. One of these veins crosses the slope a little above the Phoenix tramhouse with a course about N. 58° W. A fine-grained porphyry dike in the quartzites is cut by this vein.

South Park fault.—A comparatively minor fault-fissure is occupied by the South Park vein crossing Silver Creek. On the north bank across from the tunnel mouth the fault is very plain, for it brings porphyry against calcareous shales and gray sandstones. The strike is here N. 75° W., and the dip N. 15° E. at an angle of nearly 80°.

The general course of the fault is, however, much more nearly east-west, as determined at several places. It is occupied by a quartz vein throughout its known length. A tunnel on the north bank of the creek, perhaps 100 yards west of the South Park tunnel and running nearly north, strikes the fault vein 60 feet from the mouth, and in the stopes the fault is seen to be nearly east-west and almost vertical. This tunnel quickly cuts through the base of the porphyry sheet, revealing the sediments under it, dipping with the usual structure, and thus proves the dislocation on the South Park fault at this point to be about 50 feet. The exact amount can not well be determined, for the base of the porphyry north of the fault is not well exposed.

The fault runs just a few feet north of the little railroad cut in the ridge to the west. A shaft was sunk on it near by. In the railroad cut some mineralized shale beds on the north side yielded pay ore, but on following them into the bank they were soon cut off by the fault, beyond which was porphyry.

On the western slope the dislocation of the porphyry sheet can be distinctly made out, and, less plainly, that of the Devonian limestone. One or two prospects on this side are on the fault or on veins parallel to it, but are too shallow to demonstrate which it may be.

The course of the South Park fault must carry it to an intersection with the Smelter fault before reaching the river, but on the west side of the Dolores there is in all probability a profound faulting on a line N. 60° to 70° W., bounding the Algonkian schists on the southwest. This fault is considered as the Smelter fault and has already been described.

To the southeast of Silver Creek the South Park tunnel follows the vein for about 500 feet, and beyond that point the fault is unknown either upon the surface or in prospect workings, unless one of the three prospects, now inaccessible, shown on the map between 9,300 and 9,450 feet, may be upon it. With the multiplicity of veins occurring in this vicinity the assertion of such identity is hardly justifiable in the absence of definite evidence.

The course of the South Park fault eastward would bring it near the western boundary of the Algonkian quartzite mass as represented on the map. But it can not be assumed that this fissure becomes the main fault on this side of the quartzites, for the reason that the Hermosa calcareous shales, etc., come against porphyry at the mouth of the tunnel, as on the northwest bank of the creek, and hence the fault limiting the Algonkian quartzites must come down to Silver Creek somewhat east of the mouth of the South Park tunnel. The facts concerning the boundary of the Algonkian quartzites are presented in a later section.

Area between the Smelter fault and Silver Creek.—The western part of this wedge-shaped area is quite simple in structure. The lowest Hermosa strata dip under the porphyry sheet shown by the map, and

appear to be underlain by quartzites of the same dip and strike. It has been explained in Chapter II that the age of these quartzites is more or less uncertain, and in the preceding section of this chapter it has been stated that they are traversed by several north-south veins, some of which may have much greater importance as fault lines than appears demonstrable on present observations.

To the east of these cross fissures is a small triangular space concerning which very little is known, since the surface is almost wholly covered by soil and wash. It lies between areas of Algonkian quartzites, but the evidence of prospect shafts seems to prove that quite different materials must be present in this ground. A shaft just below the wagon road and less than 200 yards west of the railroad trestle over Silver Creek has penetrated a porphyry of dark-green color which is so much altered and so richly impregnated with pyrite that its character is not readily recognized. This is probably a dike in sediments similar to those of the next prospect to be referred to. The shaft was inaccessible.

Southeast of the above shaft, on the other side of the creek and below the railroad, another shallow prospect reveals shaly beds highly impregnated with pyrite and much altered to a dark-green material. The shaft was full of water and the structure at this point could not be ascertained.

On the bank of the creek, midway between this point and the Richmond tunnel, is a small outcrop of marbleized limestone, in irregular and obscure contact with quartzite, in the stream bed. This marble resembles in some degree the Devonian strata in Rico, and this is the only place in Silver Creek where any such material has been seen.

In the Bertha tunnel, supposed to be on the line of the Silver Creek fault, green pyritic material has been found similar in character to that at the prospect shaft, near the railroad trestle, and it is notable throughout the Silver Creek area that the shales adjacent to veins are often mineralized in this manner.

Silver Creek fault. This name is applied to a fault which has not been seen, but which it seems necessary to assume as passing down the southeast side of Silver Creek, from near the South Park tunnel, running just in front of the mouth of the Hibernia tunnel and thence down stream into Rico, as represented on the map. Its general course is apparently about N. 60° E., and the downthrow is on the southeastern side, and is estimated at about 100 feet. The fault is required to lower the base of the thick porphyry sheet of Newman Hill below the level of Silver Creek.

A thin remnant of porphyry caps the ridge north of Silver Creek underneath gravels of probable glacial origin. This is supposed to belong to the Newman Hill sheet, but the presence of porphyry in the railroad cut below, in irregular relations to the shales, renders this uncertain.

The porphyry sheet dislocated by the South Park fault between Silver Creek and the Grand View smelter is intruded in the lower Hermosa beds about midway between the Devonian limestone and the base of the Newman Hill porphyry. These relations are reasonably well proved by surface exposures and the developments in the Hibernia tunnel.

This tunnel runs from its mouth 412 feet S. 14° E., all of the way in porphyry, and at this point connects with a shaft from the surface, also in porphyry, except for the surface materials. At the shaft the tunnel turns easterly with quite irregular course for a distance of about 750 feet. It remains in porphyry for some 500 feet from the turn, and then passes across the lower contact of the sheet into shales and thin-bedded sandstones with strike N. 55° – 60° E., and a dip of 15° or 20° to the west of south, a normal structure for this part of Newman Hill. Passing on in easterly course, the tunnel penetrates another porphyry sheet, and at the extremity of the workings, at the time of visit, the strata below that porphyry had been found. It is supposed that this lower sheet can be correlated with that on the surface north of Silver Creek.

The evidence of the Hibernia tunnel is apparently substantiated in the workings of the South Park mine, but the great number of fractures revealed in this tunnel and the southerly drifts from it have so complicated the relations of the formations that it must be confessed that they are not entirely understood. But the presence of a minor porphyry under the main sheet is clear.

The map represents this fracture as terminating at the South Park fault. It is true that a fault vein exhibited at the Bertha tunnel, near the Richmond, is about in the line of the Silver Creek fault, but the rupturing on that fissure appears to be a part of that by which the Algonkian quartzite block on the southeast was thrust up.

Faults bounding the quartzite mass south of Silver Creek.—The mass of Algonkian quartzites rising from Silver Creek to a height of 450 feet above the stream and extending from the Laxey tunnel southwest for about 1,200 or 1,300 feet is regarded as a block surrounded on all sides by faults. But so completely are the boundaries of the mass concealed by surface materials that very little direct evidence of the exact position of the faults can be obtained. At the Laxey tunnel the eastern boundary of the quartzite appears as a fault vein, the general course of which is N. 15° W. To the east of this fault appear sandstones and shaly beds of the lower Hermosa, which extend eastward into Allyn Gulch, appearing at the mouth of the gorge below the porphyry sheet. To the west of this line quartzite outcrops extend well down toward Silver Creek.

From the Laxey tunnel southwest the massive quartzite exposures are bounded by slide rock, chiefly of monzonite-porphyry, at a level above 9,500 feet. As this is the normal position for the Newman Hill

porphyry sheet, and no other important body of that rock occurs on the slopes above until the summit of Dolores Mountain is reached, it seems certain that the upper boundary of the quartzites is near the visible limit of the outcrops and must be a fault with a throw of 600 or 800 feet at least.

At the southern extremity the line between porphyry and quartzite is closely defined though not actually exposed. It gradually descends the slope and is nearly in line with the South Park fault, as has been mentioned in describing that break. But from the fact that the Carboniferous strata are seen at the mouth of the South Park tunnel with the structure exhibited to the north of the creek, it must be concluded that the necessary fault bounding the Algonkian quartzites reaches the creek level above the mouth of the tunnel. It is probably within a hundred yards of the tunnel, where surface débris comes down to the creek level, and the system of fissures noted in the Algonkian quartzites from the Richmond tunnel down to the limit of the outcrops may be regarded as in general parallel to this fault.

The hypothetical fault separating these quartzites from the supposed Devonian area north of Silver Creek is necessary because there is no indication of any structure which could possibly bring those quartzites over the Algonkian area. The vein followed by the Bertha tunnel, a little west of the Richmond tunnel, is assumed to be on this fault line. To the southeast of it the quartzites are brecciated and sheeted in a most marked degree.

Telescope Mountain fault.—A great fault, the course of which, as shown on the map, is somewhat hypothetical, must cross the ridge from Telescope Mountain to Nigger Baby Hill at about 11,500 feet and run in a general westerly direction down the slope along the southern line of C. H. C. Hill. It is possible that the faulting is not upon one fissure, as represented, but rather upon a fault zone. A part of the existing structure may also be due to steep dips, as will be explained below, but the observations made are too meager to justify the representation on the map of anything but the simple hypothetical fault. The total dislocation to be accounted for amounts to between 1,750 and 2,000 feet, as indicated by the considerations to be presented.

The Rico formation crosses the west slope of Nigger Baby Hill with a dip which will carry it against the hypothetical fault of the map at somewhat below the level of 9,750 feet. A ledge of massive blue Hermosa limestones, outcropping near the Premier mine, occurs at this level; hence it is plain that a break amounting to the thickness of the Rico formation (300 feet) plus the upper division of the Hermosa (400 feet) and an unknown amount of the massive limestone series, a total which may exceed 1,000 feet, must exist in the covered space south of the limestone outcrops.

The map shows that the Rico beds reappear in the cliffs of Telescope Mountain at about 11,000 feet, here possessing a northerly dip, which

would bring them onto the southwest ridge of Telescope Mountain at somewhat above 11,250 feet. The landslide area of this ridge unfortunately extends much above this level, but, as exhibited by the map, there is an area of exposures on the western slope surrounded by landslide debris. The strata of these outcrops are greenish shales and sandstones with light-colored grits, and can belong only to the upper part of the Hermosa. The Rico beds must, then, actually reach the crest of the Telescope Mountain ridge at about 11,500 feet, and the great fault limiting them on the south must cross the ridge nearly as represented, and throws them down about 2,000 feet to their position south of C. H. C. Hill.

That a fault of much importance crosses the southeastern face of Telescope Mountain is furthermore evident from the great apparent thickness of the Dolores Red beds here present. From the summit of Telescope Mountain to the base of the Dolores formation in Silver Creek the difference of level is about 2,250 feet, and as the strata have a general northerly dip of 10° to 15° all the way up the slope, this represents an apparent thickness of nearly 3,000 feet of Dolores strata. Moreover, the horizon at the summit of the mountain is some 600 feet below the top of the formation, as shown by the situation of the Rico beds on the western slope in the strike line. The apparent thickness of the Dolores formation, therefore, reaches nearly 3,600 feet, if no fault is taken into account; and as this is just about double the real thickness, there is a dislocation, or a series of dislocations, crossing the southeastern slope of Telescope Mountain amounting to nearly 1,800 feet by this measurement. It is plain that if there is a single fault with a throw approaching this amount it must be situated very near the line adopted, to avoid the appearance of the La Plata sandstone on the south and of the Rico formation on the north.

Three lines of evidence thus agree in indicating the general course and the amount of this important dislocation. The fault of the map is made to coincide with a quartz vein discovered on the southeast slope of Telescope Mountain, traversing Dolores Red beds, but in the nature of the case it is impossible to measure the dislocation in the midst of this great series of alternating beds of similar character, without perfect exposures, and this slope, while steep and presenting many cliff outcrops, is largely grassed over. The vein in question is exposed in two or three shallow prospects, and in them courses N. 80° E. and has a northerly dip of about 60° . Its eastern projection must apparently run between two porphyry masses, the lower of which is crosscutting and approaches so near to a more regular sheet above that if the strike of the fault did not carry it through a small covered space between them, the two porphyries might reasonably be supposed to unite.

The Hermosa shales and sandstones of the isolated exposures on the western slope show that there is much fissuring and that reverse dips

prevail, at least locally, in the area just north of the hypothetical fault line in the region obscured by landslide débris. Several veins traverse this block, and one of them is a fault N. 60° E., nearly vertical, and with a displacement of more than 60 feet, though the direction of downthrow was not determined. Several caved tunnels indicate other veins in this mass. The structure is quite at variance with that normal to Telescope Mountain above or to the ridge on the south. In the northernmost outcrops the strike is nearly N. 80° E., and the dip is southerly, varying from 3° to 15° in different exposures. Toward the south the strike swings to nearly northwest-southeast, and the dip reaches an observed maximum of 35° SW. Irregularities similar to those just mentioned could not be detected in the Red beds on the south slope of Telescope Mountain, and it is therefore quite possible that northwesterly fissures, in general parallel to the Blackhawk fault, limit the structures seen in the area of Hermosa strata above mentioned.

The western extension of this fault passes into the obscured area of Darling Ridge, and even more than in the cases of the Nellie Bly, Last Chance, and Smelter faults there is no known evidence showing the manner in which it dies out. It may be cut off in its principal dislocation by other faults. So far as the structure of Darling Ridge is exposed by mine workings, there is no suggestion of any great displacement north of Aztec Gulch.

Faults of C. H. C. Hill. It has been suggested that the Blackhawk fault traverses the landslide-covered area of C. H. C. Hill to a union with some one or more of the faults known near Burns. It is also probable that other fissures upon which there has been more or less dislocation cross this space nearly parallel to the Blackhawk fault. Some one of these faults may represent the northeast boundary of the landslide, parallel to the notable line of cliffs seen in Pls. XV-XVII. A slickensided surface seen at about 10,750 feet, at the base of these cliffs, may represent such a fissure.

But the evidence of nearly continuous ore deposits, which are in general parallel to the bedding through a large part of the middle area of the hill, proves that no great amount of faulting can exist except in the region of the great Telescope Mountain fracture.

Faults of northeast-southwest trend cross the northwest ridge from Telescope Mountain and doubtless extend some distance under the landslide débris.

Other faults.—The remaining faults of the area covered by this special map possess no marked importance not sufficiently indicated on the map. They are found in all directions from the center and run with various courses. Beyond the Rico Mountains proper faults have been noticed, particularly to the west and northwest. Nearly west of Eagle Peak a fault of about 500 feet crosses the West Dolores River nearly east and west.



LOOKING UP HORSE GULCH FROM SANDSTONE MOUNTAIN.

To show the sandstone area on the north side of the gulch contrasting with the ledges of rock in place nearer to the point of view. In the bed of Horse Gulch may be seen the slide bench at the Pizzara mine.
Photograph by Cross.

CHAPTER V.

LANDSLIDES.

By WHITMAN CROSS.

GENERAL STATEMENT.

For several miles about Rico in nearly all directions there has been, in Pleistocene time, a great deal of landslide action of a character rather peculiar to this region. As a result of this extensive movement the physiography of certain tracts has acquired characteristic details and the normal geologic structure has been more or less completely obscured. The movements in question have taken place since the valleys and mountains received their general form and relations as now seen, but although subordinate and modifying slips have repeatedly occurred down to the present time, the greater part of the phenomena probably date back to early Pleistocene.

While some of the slide areas embrace square miles of surface, the action seems to have been much more superficial than the landslide movements of the neighboring Telluride quadrangle, described in the Telluride folio. Even in the most continuous areas there is seldom evidence of large bodies having moved en masse, but there seem to have been many distinct slides, which, through disintegration by various agencies, have come to grade into one another and thus to form a confused mantle of fragmental material covering the solid rock. As a whole the landslide phenomena constitute one of the most important elements in the local geology. To them is due the absence of clear geologic structure in areas adjacent to those in which the formations are most plainly exposed. And even with the most careful examination there are some considerable spaces within which the structure of the underlying formations can be ascertained only by the aid of tunnels and shafts driven in the course of the mining development of the district.

In the past prospecting of the Rico Mountains the failure to recognize the true significance of the landslide phenomena and to perceive their extent has led to very great loss of time, labor, and money.

The first recognition of the landslides, in the course of this survey, was made by Mr. Purington, while he was engaged in the preliminary work on the ore deposits in the summer of 1896.

ENUMERATION OF LANDSLIDE AREAS.

The town of Rico lies nearly in the center of the district characterized by landslides. The largest continuous slide areas are in the valley of Horse Creek, and they extend far up the northern and southern slopes. On the northern side a slide surface extends from the creek bottom to an elevation of nearly 11,400 feet toward Sockrider Peak, including Sinbad Hill. On the south side almost the entire surface from the south fork of the creek eastward to the end of Darling Ridge is obscured, as to its structure, by landslide material. The crest of Darling Ridge is shattered and superficially dislocated along almost its entire length from the Uncle Remus claim to the river.

The north side of Burnett Gulch presents little but landslide phenomena from an elevation of 11,250 feet on Expectation Mountain to the mouth of the creek. West of the town of Rico there are small areas of landslide contiguous to the ridges above named, but associated with common slide or wash and other surficial masses.

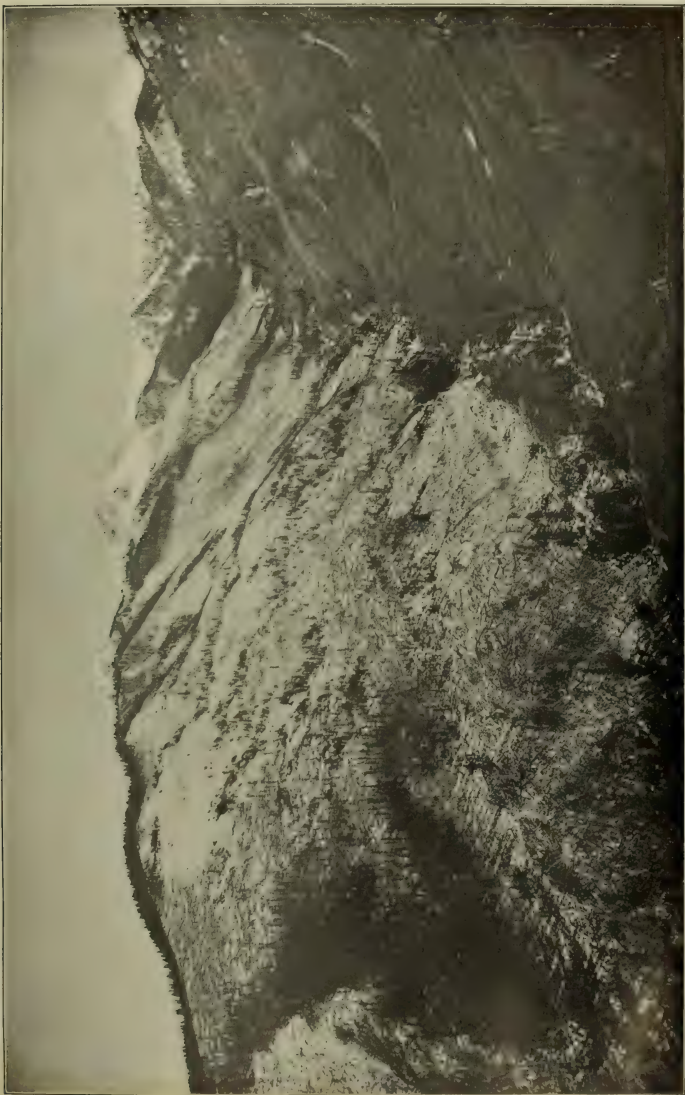
The eastern mountains of the Rico group, south of Silver Creek, exhibit landslide action in numerous places, to be described, but no large areas are there found. Dolores Mountain, Blackhawk Peak, Whitecap Mountain, and other localities present small landslide areas of more or less distinctness. Newman Hill has received fragmental material of this origin from the higher slopes of Dolores Mountain, but the mingling of surficial masses of different origin is here so complex as to subordinate the importance of the landslides.

Telescope Mountain and the slopes of Nigger Baby and C. H. C. hills have suffered some of the most extensive landslips of the region, the present topography of C. H. C. Hill being largely a result of this movement.

Beside these larger areas there are many others, somewhat farther removed from Rico, in which landslides of limited extent have occurred. Stoner Creek, Landslip Mountain, and the ridge east of Whitecap Mountain are the most important of these.

NORTH SIDE OF HORSE GULCH.

The principal landslide area on the north slope of Horse Gulch is represented on the map. It is one of the most clearly defined slips of the region and has very characteristic details of topography. In Pl. IX is given a view of this slide area as seen from Sandstone Mountain. On the right hand are seen the normal ledge outcrops of massive



DARLING RIDGE FROM SANDSTONE MOUNTAIN.

Illustrates the uneven topography due to many small landslide blocks. Photograph by Cross.

Dolores and Rico strata, which are suddenly interrupted on the line of a ravine coming down to Horse Creek just above the Puzzle mine. From this ravine westward the slope possesses the irregular features of knoll, ridge, trench, and hollow of various shapes, found on all the landslide surfaces, and exhibited in some measure by the illustration. The general contrast between this area and the adjacent slopes is very striking from all points of view.

The greater part of this slide area is now covered with grass or an aspen growth, and the direct evidence as to the character or attitude of the formations beneath is found in local outcrops, small slides of recent date within the main area, the prospect holes, or the physiographic details found by observation to be characteristic of landslide surfaces. Along the landslide bank of the ravine, on the eastern border and below the level of 10,050 feet, the loose materials have at several places been washed away, revealing ledge outcrops of greenish Hermosa sandstone. These exposures belong to different blocks, some of them 50 feet in visible length, the strike and dip changing abruptly from block to block, and never corresponding to the normal structure found on the east side of the ravine. Some of the blocks show a nearly vertical dip, while in others the beds dip 40° or more, usually down the slope.

In the view shown in Pl. IX may be seen a bare spot, 400 or 500 feet above Horse Creek, which is due to the recent falling away of a part of what was doubtless a wooded or grassy slope like that above and on either side. In this way a jumble of formations has been exposed, which is probably typical of the relations existing in much of this slide mass. The exposure reveals ledges of much-shattered sandstone, shale, and porphyry, dipping in most widely varying directions. The change from one block to another is abrupt, by a fracture or crushed zone, and the original relation of the various formations to one another can not be definitely ascertained. Porphyry predominates along a zone at the top of this exposure, and the first inference is that there is a sheet of porphyry here which may be traced for some distance, but in fact several structural phases of porphyry are here mingled, and it is questionable whether any one sheet can be identified at this locality.

This exposure serves to illustrate the manner in which the complex of a slide area gradually disintegrates still further, and must eventually lose all its distinctive features. Through the shattered condition of such landslides they become saturated with water, and at times different portions will slump away and break up into a mass of ordinary avalanche or slide material. Each fresh break furnishes a point of attack for the elements of frost, rain, springs, snowslides, etc., and the destruction of the shattered mass goes on more rapidly.

All over the central part of this landslide area there are very marked knolls and ridges, with shattered and irregular rock outcrops, back of

which are the V-shaped trenches marking the fracture lines of individual slide blocks. These are almost always partially filled in, and fresh fractures in the soil are rare. The trenches are so independent of any normal drainage system that their origin seems open to no question. Some of them are shown on the map, but any adequate expression of this topography would require a much larger scale and a contour interval of 25 feet or less. Hollows without drainage outlet are common on the lines of trenches, some of them being shown by the map.

The prospect tunnels or shafts which have been run into the landslide area all show greatly disturbed strata, and most of them were caved in at the time of visit. It is safe to say that none of them penetrated to solid rock in place beneath the slide. Exception may be made in the cases of some of the tunnels starting near the borders of the slide area, which probably run under the fragmental slide debris.

Along the base of this landslide area the common wash and talus obscure the actual limits of the slide, but it probably extended quite to the creek bed. On the west it is apparently bounded by the ridge east of the gulch heading under Sockrider Peak, although but few solid outcrops exist near the line drawn on the map. The eastern limit is sharp for the greater distance, but becomes lost above in the accumulations of debris from snowslides and other agencies.

The landslide area ends upward in a point under the cliffs of red Dolores sandstones at about 11,400 feet. Chaotic slide blocks, which are rounded and more or less grassed over, cease at about 11,000 feet, and between this and the solid cliff line there is a small area of more angular blocks of red sandstone and porphyry in which there is often a dip toward the mountain. Each of these blocks is clearly marked, and fissures of dislocation between them are like open faults with a measurable throw of 50 feet or less. Some of these blocks have fallen from the cliff in comparatively recent time, and fissures which may serve as boundary cracks of future slips are to be found here and there in the cliff.

SOUTH SIDE OF HORSE GULCH AND DARLING RIDGE.

The area from the bed of Horse Creek to the crest of Darling Ridge and from the south fork of the creek to the Dolores River contains so few outcrops of rock in place that it may be treated as one landslide area. No other section illustrates so well the conception to be presented as to the origin of the landslides of the Rico Mountains.

Crest of Darling Ridge.—The formations of the crest of the ridge are obviously not derived by sliding from any other source, but they are in many places so shattered by important fractures running in all directions, and the blocks bounded by these fractures are so plainly



LANDSLIDE AREA ON THE NORTH SIDE OF HORSE GULCH, AS SEEN FROM A POINT WEST OF THE "BLOWOUT."

Beyond the confused topography of the landslide area are seen the ledge outcrops of Sandstone Mountain. Photograph by Cross.

dislocated superficially that the whole mass may be considered as broken and not strictly in place. The best illustration of the shattering is in the massive stock of monzonite opposite the head of Iron Gulch. By a glance at the map it will be seen that there are here a number of sharp pinnacles and knolls, to which one or two contours have been given. But a map of this scale fails to show the number of these knobs, and the hollows, curving ravines, and irregular depressions between them, belonging to no drainage system. The rock of the knobs is often fresh, but much shattered, and the hollows between are rounded by the gravel of disintegration washed into them. This topographic detail, while on the top of the ridge, is similar to that on the landslide slopes. Below these pinnacles on the slope to Horse Creek are some other knobs of monzonite, and the surface is covered by talus and landslide heaps nearly all the way to the creek bed.

Eastward from the principal area of monzonite, along the crest of the ridge, there occurs a tongue of sedimentary rocks, then a second and smaller area of monzonite, and below that a great series of strata with intrusive porphyries. At several points the primary boundaries of these formations are more or less clearly exposed, and, as represented on the map, it must be assumed that the normal geology of this ridge would show the Hermosa and Rico formations including several porphyry sheets, and all penetrated by a single branching stock of monzonite or by two distinct masses. But from the crest, or near it, down to Horse Creek the surface is a mingling of landslide blocks, large or small, intact or in process of dissolution, and geological boundaries showing the original relations can not be traced.

The slope below the monzonite of the crest is mainly covered with this rock. Sediments and porphyry are mingled with the monzonite over a considerable space, but practically no monzonite occurs east of the ravine heading opposite the easternmost exposure of monzonite on the ridge. The mingling is not as in ordinary talus below cliffs. A knob or ledge at one point is perhaps wholly of one rock, or of sandstone with a porphyry sheet, while an adjacent knoll is equally pronounced of monzonite.

Physiography of the slope.—The general physiography of this ridge is seen in Pl. X. Its features are not large enough in most parts to allow satisfactory expression with 50-foot contours. The main feature is the great number of trenches, most frequently parallel to the contours, or near it, yet often running diagonally across the slope. As a rule no trench is persistent for a long distance, being cut off by some other trench. A few of these lines are ravines of importance, shown by the maps, and at several places they run up to or cross the crest of the ridge.

Outside of the trenches are mounds, knobs, furrow-like ridges, or benches, and in these are not infrequent ledge outcrops which by vari-

ous dips and strikes and the shattered condition of the rocks add to the evidence of landslide action. Pl. XIII represents one of the characteristic trenches, at an elevation of about 10,500 feet, between the south fork of Horse Creek and the head of the "blowout." Many of this character exist on the adjacent steep slopes. Beyond the trenched surface part of the uneven profile of Darling Ridge is seen, and in the distance Telescope Mountain and the upper part of C. H. C. Hill.

From elevated points on the north side of Horse Creek with a favorable light one can count 25 or 30 lateral trenches, similar to that of Pl. XIII, on many section lines between the creek and the crest line of Darling Ridge. No regular drainage channel exists on the south side of Horse Gulch between the river and the ravine opposite Sinbad Hill.

On the slopes between the trail leading to the Magnetite mine and the lower part of Horse Creek there are many outcrops showing massive fossiliferous limestone and associated sandstone. Some of these are extensive enough to suggest that they represent rock in place. The prevailing structure in these outcrops is a gentle dip down the slope, but the abrupt changes in dip and in character of rocks, with the presence of the usual trenches back of or diagonally crossing the slopes, make it clear that no one ledge examined can safely be considered as in place. It is probably true that in some cases, especially on the higher slopes, the dislocation is not very great, but it is sufficient to make correlation of different outcrops very uncertain except upon a basis of exhaustive study of the whole ridge.

Landslide block at the Puzzle mine.—That there has been landslide action in Horse Gulch has been evident to all familiar with the ground about the Puzzle mine and with the experience of those who have tried to find the continuation of the ore body originally discovered in the Puzzle. But the extent of the slide has not been appreciated.

The view given in Pl. XIV shows in detail the character of the bench in the valley where the original discovery of the Puzzle ore body was made, and in Pl. X may be seen the general relations of the locality to the landslide surfaces already discussed, on both sides of the creek.

The ore body of the Puzzle mine, a replacement of a limestone stratum by galena, etc., was found in a ledge outcrop facing the stream bed, on the right hand of Pl. XIV, and opposite the buildings shown in the illustration. The strata of the ledge included crinoidal limestones typical of the middle division of the Hermosa Carboniferous. The beds have a general dip downstream, but they are irregularly dislocated on fissures now open, and in places the dip is southerly at a low angle. The structure is at variance with that normal to the gulch, as seen on the north side.

The ore was traced under the bench, but it was soon cut off by breaks on the east, south, and west. A shaft sunk in the little trough at the base of the snow-covered slope, near the building shown in Pl. XIV,



DETAILS OF LANDSLIDE TOPOGRAPHY IN THE AREA ON THE NORTH SIDE OF HORSE GULCH.

Photograph by Cross.

passed into stream gravels at a depth probably less than 50 feet, proving that this ore-bearing block has slipped down from the slope above.

A few yards to the west of the break limiting the ore in the main Puzzle workings a continuation of the ore body was found in the Puzzle Extension and traced, with several small dislocations, to a more extensive fracture, beyond which the present developments have failed to discover it. A similar ore-bearing horizon has also been formed in the M. A. C. mine on the east, but so limited by cross fractures, including apparently old faults, that the identity of the ore body with that of the Puzzle mine is open to question.

The workings on the original Puzzle ore body, the efforts to trace it beyond the breaks on all sides, and the surface configuration of the gulch slope, all give evidence that there has been complex shattering of the strata in this vicinity, and that the formations thus far penetrated in the prospect tunnels and shafts are in rather small and irregular landslide blocks. Nothing as yet discovered indicates the depth to which this superficial dislocation extends, nor the position of the formation in place from which the ore-bearing block of the Puzzle mine was detached.

"*The Blowout.*"—Another locality in Horse Gulch worthy of special description is the so-called "blowout," situated on the southern slope between 10,000 and 10,500 feet, and north of the monzonite pinnacles of Darling Ridge. The map shows closely spaced contours in a drainage channel at this point and a curving ravine above it, heading between the two monzonite areas of the ridge crest. In fact, this ravine heads on the flat top of the ridge, and is but one of several very marked landslide trenches in that neighborhood. The trench shown in Pl. XIII runs eastward to the head of the blowout.

The main blowout means in this case, as in many others, a locality of intense mineralization of the rocks, followed by decomposition and oxidation and hydration of the ore particles, mainly pyrite, producing strong coloration of the rocks as now exposed. The existence of the blowout at this particular point is due to local erosion revealing an internal condition of the rocks which is not local but extends for some distance along this slope. The nature of this erosion is shown by some smaller adjacent exposures, where loose fragmental material has become softened by springs and has given way, flowing as a mud stream down the steep slope, leaving a hollow, which must rapidly enlarge once the point of attack for frost and running water has been developed. Below the main blowout a fan or alluvial cone of abnormal size indicates a rapid transfer of material.

Examination of the rocks exposed at the blowout reveals the presence of monzonite and syenitic porphyry in so confused a relation that, with the complications resulting from landslide action and the intense alteration, it is impossible to trace either rock except by fresh fracture at

every step, so that no positive statement can be made as to the original rock in place at this point. From study of the best exposures in this vicinity it appears probable that there is here a stock of monzonite, with associated porphyries, penetrating sediments which contain intrusive sheets of the common porphyry of the region, and that still further complication may be due to cross-cutting porphyry masses connected with the eruptive center at the forks of Horse Creek.

Western limit of the landslides.—The western limit of the continuous landslide area on the southern slope of Horse Gulch is rather indefinite, but lies on the east side of the south fork. It is here obscured by the presence of surficial materials of later origin, part of which are derived from the head of the south fork, while other portions are the result of disintegration of the landslide blocks. But from the edge of the porphyry cliffs of the little canyon it is only a short distance up the slope to trenches and other physiographic features of landslide origin.

The southern limit in the south fork is the line of the map running down from the saddle near the Uncle Remus.

The force by which the rocks of Darling Ridge were so shattered, producing the fissures which limit the main landslide blocks, was also exerted in less degree to the westward, and landslides of small size have taken place in the angle between the south and west forks of Horse Creek, on the end of the ridge from Anchor Peak. The chief evidence of this action is in more or less distinct trenches of general east-west direction, below which the strata are broken up and disturbed in strike and dip.

TELESCOPE MOUNTAIN AND C. H. C. HILL.

The area embracing Telescope Mountain and that part of its western slope known as C. H. C. Hill contains some of the most distinct landslides of the district, yet presents in them the clearest evidence as to the superficial character of the phenomena. The movement is still in progress at certain points. The slides have greatly hindered the economic exploration of this tract, and have effectually concealed certain structural features which are of great importance to the understanding of the geology of the Rico Mountains. Several of the important fault lines whose presence is assured can not be well defined until mining operations expose the structure in the solid rock beneath landslide masses of unknown depth.

Telescope Mountain.—The structure of the upper part of Telescope Mountain is very clear, from the excellent exposures of the red Dolores strata on the summit and for some distance down the ridges leading out in various directions. On the west and southwest the manner in which superficial landslides obscure the geology is well illustrated.

The summit of the mountain is made up of crumbling red sandstones with a dip toward the north, and while the beds do not form



LANDSLIDE TRENCH ON THE SOUTH SLOPE OF HORSE GULCH.

Telescope Mountain in the distance. Photograph by Cross.

prominent outcrops some of the principal beds can be traced nearly around the peak. On the northwest ridge some variations in strike occur, which may be due to ill-exposed minor faults, but at about 12,000 feet the rocks outcrop in blocks which are separated by open crevices and the tilting in different directions shows superficial dislocation. From about this point a large amount of avalanche material has fallen down the northeast slope into the head of McJunkin Creek, and a less amount westward to C. H. C. Hill. Increasing evidence of minor fractures and dislocations is found farther down the ridge, and about where the fault crosses, at 11,600 feet, there is much confusion, large and small blocks lying in chaotic relations. There has been more or less land-slipping all along this northwestern ridge, but it is insignificant beside that within the designated areas of the map.

The western face of Telescope Mountain is shown in Pl. XV, which brings out the characteristic landslide topography in contrast with the normal. On the left hand is the cliff which faces C. H. C. Hill all the way from a point under the summit of Telescope Mountain to the Dolores River. This cliff is interrupted a little southwest of the summit by an avalanche path from the head of the landslide area.

This apex of the landslide is at 11,800 feet, just below ledges of an encircling porphyry sheet. Here are knobs of Dolores sandstone tilted in all directions, some of them almost ready to follow the well-worn track of many predecessors, which leads far down the slope. Blocks so small as those now poised break up into avalanches as they fall and do not reach any great distance, but in the past the slope has been such or the falls have been of such magnitude that the trail of this red material can be followed to the river.

From the same level of 11,800 feet the slides have descended south and southwest toward Silver Creek or down the ridge toward Nigger Baby Hill. But this fall has been less in volume and on the south slope the material has disintegrated and has become grass covered and smoothed out. But the line between the cliffs below and this landslide surface is very distinct, running along at about 11,000 feet. On the crest of the ridge there is the usual landslide topography, especially for several hundred feet below the ledges of porphyry just above the slide area.

C. H. C. Hill.—The triangular space between the Dolores River, the southwest ridge of Telescope Mountain, and the cliff line, seen in Pl. XV, is known as C. H. C. Hill. It is really a broad hollow on the slope of Telescope Mountain. Its character and relations are shown in Pls. XV and XVI. In the former view the peculiar physiography of the surface is well expressed, and in the latter the relation to the Dolores Valley may be seen.

While the landslide trenches, ribs, and knolls are very plain over nearly the entire area of C. H. C. Hill, the examinations have shown

that the landslide phenomena are, on the whole, much more superficial than might reasonably be inferred from the physiography. The peculiar topographic features of the hill are principally due to landslides, but the ground, which has slipped in blocks, has been in part covered by avalanche débris and common talus. The disintegration of crushed rocks has yielded soil, and over much of the hill a growth of spruce and aspen conceals everything.

The part of the hill in which normal landslide phenomena are now most distinct is a broad band parallel to the cliffs on the northeast. The most pronounced trenches run in general parallel to these cliffs, and it seems probable that an observed sheeting of the strata in a north-west-southeast direction has caused not only the cliffs of to-day but numerous fissures bounding thick plates or blocks of rock which have fallen en masse at various times. At one place observed, the present cliff exhibits a very distinctly polished and striated surface, which may be due to landslip action.

In the zone below the cliffs there are a number of knobs or knolls on which are outcrops showing the composition of the mass. Most commonly a complex of huge blocks is found, which may be in chaotic relations or may have a rude correspondence in dip and strike, though fissures of small dislocation run through in irregular manner. The strata of such a knoll are either predominantly of one kind or clearly belong to one part of the sedimentary series. One of these prominences, showing mainly limestone, is situated just south of the Pigeon Mine. As the higher cliffs above the Pigeon are of the upper sandstones and shales of the Hermosa Carboniferous, it is evident that this block has not slid far down the slope, but the shattered condition of the limestone is testimony that it has undergone the disturbing action of the landslip period.

In Pl. XVII is shown one of the knolls of landslide origin, with a sink and bench back of it, the cliff representing either the face from which this slide came or one back of the cliff of the slide epoch.

Damming of Dolores River.—The bench between the wagon road and the river, extending from Burns to a point below the mouth of Horse Creek, is probably composed entirely of landslide material. As shown by the map, the river for some distance above Burns flows over a very flat, broad bottom. Immediately below Burns the stream passes into a little gorge, bounded on the western side by cliffs of limestone and sandstone and on the east by a steep bank made up of limestone, sandstone, and conglomerate, in a wholly confused mass of coarse slide. No outcrops of rock in place occur on the eastern side along the face of this bench, and the railroad cutting reveals most clearly the chaotic mingling of various rocks. In Pl. XVI is an illustration of the abrupt ending of the flat at Burns against the bench of landslide material.

It seems necessary to assume that the present alluvial flat at Burns is



LANDSLIDE BENCH AT THE PUZZLE MINE, IN HORSE GULCH.

The present bed of the stream is on the right of the bench. A shaft to the left of the cabin seen in the center of the view passed into stream grave's Photograph by Cross.

due to the damming back of the river by the slide, but it also appears probable that at the time of the slide the valley bottom was broad and of very gentle grade along the stretch now occupied by the slide bench. From the mouth of McJunkin Creek to the beginning of the gorge below Burns, a distance of $1\frac{1}{2}$ miles, the river has a fall of but 50 feet, while between Burns and the mouth of Horse Creek the fall is 150 feet in two-thirds of a mile. It is probable that before the slide the grade of the river was very even from McJunkin Creek to Silver Creek.

The excavation for the wagon road from the flat at Burns to the top of the slide bench, seen in Pl. XVI, exhibits the transition from the almost undisturbed strata near the bridge to the confused mass of large blocks forming the bench. As far as the C. V. G. tunnel, just below the road, the succession of greenish sandstones, shales, and occasional limestones is like the sequence known above the main limestone series. At about the tunnel a more disturbed condition appears, and becomes more and more pronounced southward to the ravine at the bend of the road. While the general strike of the beds continues the same the dips are variable, cross fractures, with evidence of dislocation, are common, and there has been slipping, especially on shale layers. Shearing movement, by which certain strata are obliquely cut off, is evident, and correlation of beds from place to place becomes uncertain. From the bend in the road on to the bench and along the latter there is a chaotic mixture of limestone, sandstone, and porphyry, the dips of the larger exposures being generally into the hill at various angles.

At the southern end of this slide bench, opposite Horse Creek, the exposures are of finer débris, and it is probably the accumulation of detritus by avalanche and ordinary slide, partly from far up the slopes of Telescope Mountain.

Recent slipping in C. H. C. Hill.—Evidence that motion is still in progress in the surface materials of C. H. C. Hill is abundant in the prospect tunnels and shafts of various places through the crushing or the twisting of timbers. But the best proof and illustration of the character of this movement is seen in a crevice now gradually opening at the upper end of C. H. C. Hill. This crevice extends from an altitude of about 10,400 feet to 11,000 feet. It is most clearly shown at about 10,550 feet, below the trail leading from C. H. C. Hill to the Uncle Ned saddle in the ridge from Telescope Mountain, and on the north slope of the little spur indicated by the 10,650-foot and 10,700-foot contours on the map. The direction of the crevice is here nearly east-west, curving to the southeast in the upper part of its course.

Where most distinct this fissure occurs on a northerly slope which is quite thickly wooded, and it would scarcely be noticed except that several trees on its line have been split from the roots up to 2 or 3 feet above the ground, in the manner shown in Pl. XVIII, from a photograph taken by Mr. Tower. A stump of one tree cut off at about 2 feet

above the ground has been split open since the tree was felled and the parts are now seen about 5 feet apart. According to Mr. J. O. Campbell, the tree was cut about 1894. Earth has filled in between the halves of this stump and to some extent under the split trees, indicating that the movement has been gradual. It probably began, however, before the felling of the tree, the stump of which has been split, for the two parts show that the tree was once cracked on the line of subsequent splitting and that this crack had been partly healed by growth.

The crevice may be followed for 200 or 300 feet below the split trees by a crack in the soil, seldom open for more than 2 or 3 inches in depth, although a horse's hoof will sink in for a foot or more. Above the trees the crevice was traced almost continuously across the trail and up to 11,000 feet in the southernmost of the two distinct ravines represented on the map.

Where the trees are split the crevice is at the base of a steep northerly slope, 10 to 20 feet above a little bench, and perhaps 50 feet above a marked ravine. Farther up the slope the crevice runs for some distance in the bottom of a shallow but distinct landslide trench. It crosses the trail on the south edge of some distinct outcrops of shale and sandstone, which are much broken up, but have a general southeasterly dip. Still higher the crevice was traced into the curving ravine in the isolated area of upper Hermosa shales and sandstones represented on the map, where it was lost.

Magnitude of the landslide action.—No part of C. H. C. Hill, as already defined, is free from evidence of landslides, and most of the present surface is made up of the débris of those slides, though much of it, or possibly all of it, has been rearranged by movements since the original falls. But the evidence of the mines and prospects demonstrates that rock in place occurs at or near the surface in many localities. These workings also show that the formations, which must be considered as practically in place, are almost universally in a terribly shattered condition, and while ore bodies in or near stratification planes have been traced for long distances, minor dislocations are frequently met with, and in several places abrupt breaks have been encountered beyond which the ore has not been again found. In the discussion of the fault structure it has been explained that several known faults have been followed to the borders of C. H. C. Hill, and others must be assumed as present somewhere beneath the mantle of débris, so that in the present condition of exploration it can not always be ascertained whether the breaks in ore bodies are due to faults or to the superficial fractures bounding landslide masses, some of which may be reopened fault fissures.

The amount of fragmental material encountered in tunnels varies greatly in different parts of the hill. Thus the Mountain Spring tun-



TELESCOPE MOUNTAIN AND C. H. C. HILL FROM SANDSTONE MOUNTAIN.

The landslide topography of C. H. C. Hill is shown in contrast with the cliffs of the mountain above. Photograph by Cross.

nel penetrates loose chaotic material for 440 feet before a semblance of rock in place is found. Much slide rock was found in the C. H. C. tunnel, and then it passed into greatly crushed beds, through which the structure can, however, be traced. In the Princeton tunnel much detrital material was passed through before rock in place was encountered.

In contrast to the tunnels just mentioned, the Pigeon and other mines in the northern part of the hill are almost wholly in rocks which are practically in place, though much fractured and disturbed.

The principal trench seen in Pl. XV is on the line of what is called the "big fissure" among those who have worked in the Pigeon, the Logan, and other connected claims. This is a zone of intense crushing of vein and country rock material 50 feet wide in some places, and the question arises whether or not some of the old veins—also faults in some cases—have not been opened anew during the shocks of the landslide fracturing.

RIDGE BETWEEN BURNETT AND SULPHUR CREEKS.

One of the largest landslide areas of the district is the broad ridge between Burnett and Sulphur creeks, extending from about 11,000 feet on the crest of the ridge down to the Dolores River, some 2,400 feet below. In its present condition this area affords few localities where landslide phenomena are clearly exhibited, but by comparison with other areas the landslide evidence is still most convincing, and the ridge is of much interest as illustrating an advanced stage in the history of landslide areas, when the ordinary agencies of degradation have nearly completed their work of effacing the scars caused by the successive slips, leaving little evidence in the smooth slopes of the confusion existing beneath.

The upper limit of this area is a rather sharp line crossing the crest of the ridge almost north-south at about 11,000 feet. This line is a well-marked trench of varying depth which runs back of the knoll having an elevation of 11,000+ feet, passes on the north across the flat at 11,175 feet, where a minor ridge juts out into Sulphur Gulch, and which on the south becomes a ravine, indicated on the map. On other sides the landslide has no closely definable boundaries.

The southwest slope of the ridge is smooth and rounded in features, entirely covered by grass or timber growth, and contrasts very markedly with the opposite side of Burnett Gulch, with its prominent cliffs of stratified rocks and porphyries. This contrast is striking as expressed on the topographic map, but is far stronger on the ground. The examination of this southwest slope shows no outcrops of rock in place except at the end of the ridge and very near the bed of Burnett Creek, nor are there the usual broken ledges characteristic of land-

slide blocks. Instead of this, the few exposures where the character of the underlying materials can be seen, and the scattered prospect tunnels, reveal detrital matter of the texture of ordinary wash or slide rock. No tunnel seen has penetrated to solid rock.

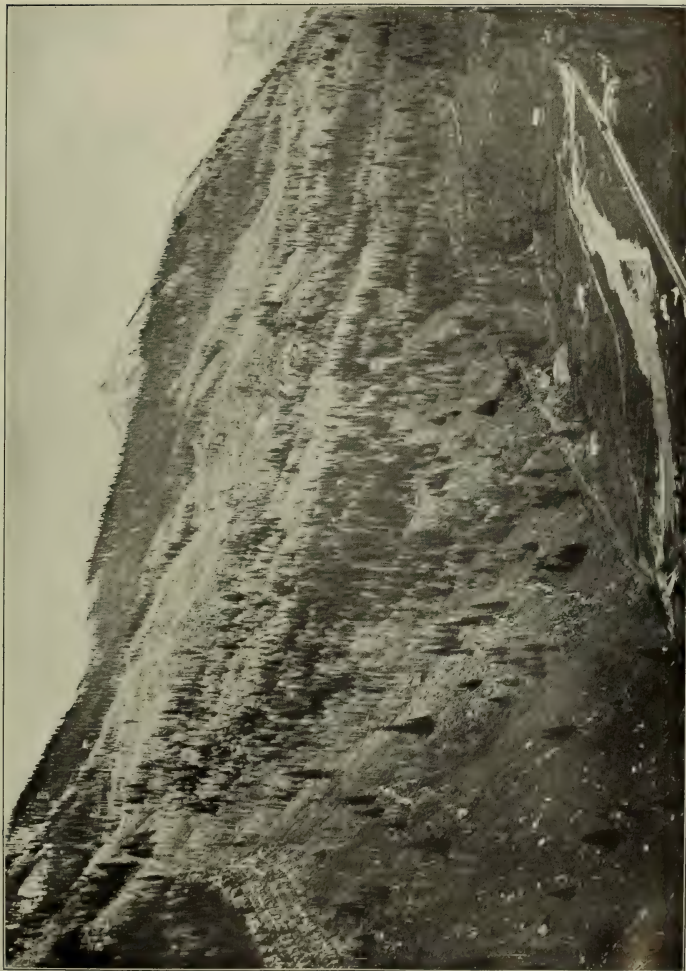
The physiographic detail of this slope is, however, most suggestive of landslides, especially when seen from some point of view like Landslip Mountain. There are many projecting knolls and local benches, irregular transverse depressions belonging to no drainage system, and general lack of persistent drainage channels. Most of this detail is of too small a scale for representation on the map.

On the northeast side of the ridge there is a steep wooded slope, upon which at several places there are very distinct trenches running horizontally or obliquely along the hillsides, with sharp, furrow-like ridges on the outer side. Some of these modify the general slope so abruptly as to indicate that they belong to quite recent slips. Outcrops of rock are rare and are always of much broken and dislocated material.

On or near the crest of the ridge leading from Expectation Mountain are the most distinct evidences of landslides. For several hundred feet below the upper limit of the area the broad top of the ridge is characterized by rounded knolls with flat or shallow depressions between them. More or less distinct ledge outcrops of sandstone, shale, or porphyry are common on these knolls, but the greatest irregularity of dip and strike is found, and the most prominent beds are clearly not continuous. The character of this part of the ridge is represented in Pl. XIX, a view from one of the upper knolls looking down the ridge. The dips observed in the mounds and knolls shown in this view are quite abnormal in most cases, being steep angles either down the ridge or to the east.

No geological boundaries can be traced across this obscure area, and this is conclusive evidence that the *débris* of the smooth slopes is not ordinary slide or talus. From the known structure of adjacent areas it is plain that the massive limestones of the Carboniferous, the Montelores porphyry sheet, and the grits of the lower Hermosa must underlie this mantle of loose material. From observations of Mr. Spencer the Rico formation may be normally in place near the 10,600-foot contour, on the crest of the ridge.

As to the end of the ridge, near the river, the evidence is not conclusive as to how large a part of the sedimentary rock seen on the steep slope below the flat bench on the Burnett trail is in place and how much is landslide material. The outcrops near the bench level are of somewhat crushed and dislocated red or greenish strata, dipping westward as a rule. The red beds seem to belong at a much higher horizon than anyone which can normally occur here. The lack of exposures for such a distance above this bench renders a verdict as to the



C. H. C. HILL FROM NEAR THE MOUTH OF MARGUERITE GULCH.

On the left is seen a ledge of rock in place, in the center the characteristic landslide topography of C. H. C. Hill, and at its base are the flood plains of the Dolores River at Burns due to damming by the landslide. Photograph by Cross.

origin of the red strata uncertain. Down near the river in fragmental material are the sulphur deposits elsewhere described, and on the bank of the river several prospects show apparent rock in place.

LANDSLIP MOUNTAIN.

One of the most perfectly exposed minor landslides of the Rico Mountains has taken place on the southwest face of a mountain on the divide south of Burnett Creek, for which the name Landslip Mountain is proposed. This summit presents to the north cliff faces of red Hermosa beds containing several intrusive porphyry sheets and dikes. The summit itself has a porphyry cap, and other small bodies occur on the ridge to the west.

From the summit of Landslip Mountain to the saddle on the west, some 300 feet lower, and from this line southward nearly to the bed of the north fork of Wild Cat Creek, the surface is covered by landslide *débris*. None is found on the north side of the divide. In Pl. XX may be seen the nature of the extreme upper part of this slide. The light-colored rock is largely porphyry, but there is also much red sandstone and shale, causing darker shades here and there.

It is plain that the larger part of the porphyry belongs to the capping sheet of the mountain, but lower sheets undoubtedly appear. The occurrence of the porphyry in sheet form in the sedimentary section is visible in many places, but accurate correlation of the shattered and disconnected exposures is impossible. The talus from the disintegrating slide blocks streams down the slope, but slide blocks of considerable size occur at intervals far down in the timber. The map shows some sinks and knolls below the part seen in Pl. XX, and the phenomena of trench and knoll are repeated as far down as the representation of the map.

DOLORES MOUNTAIN AND NEWMAN HILL.

Landslide phenomena comparable with those that have been described are of very limited extent on Dolores Mountain, and are found only on the southern and western slopes. Nearly the whole southern slope is smooth and has a veneer of ordinary wash and talus, through which small outcrops project here and there. A landslide which is of recent date, since it sharply modifies the rounded form of a grassy slope, has taken place on the small ridge between the two southwesterly ravines indicated by the map.

Above the slide bench, which is shown on the map by a bowing out of the 11,050-foot contour, the ridge has in general a very rounded outline, but near the bench is sharply sliced off by a plane having a strike N. 57° W. and dipping 40° SW. This plane extends to the bench and seems to represent the surface upon which sliding took

place. While there are no distinct rock outcrops above or near the bench, the outer face of the little shoulder below it presents much broken-up strata, in part at least of the Rico formation, in masses several yards in diameter and of discordant dip and strike in different exposures. Small transverse trenches and fissures show that this mass is disintegrating, and a train of *débris* from it leads in fact far down the slope below.

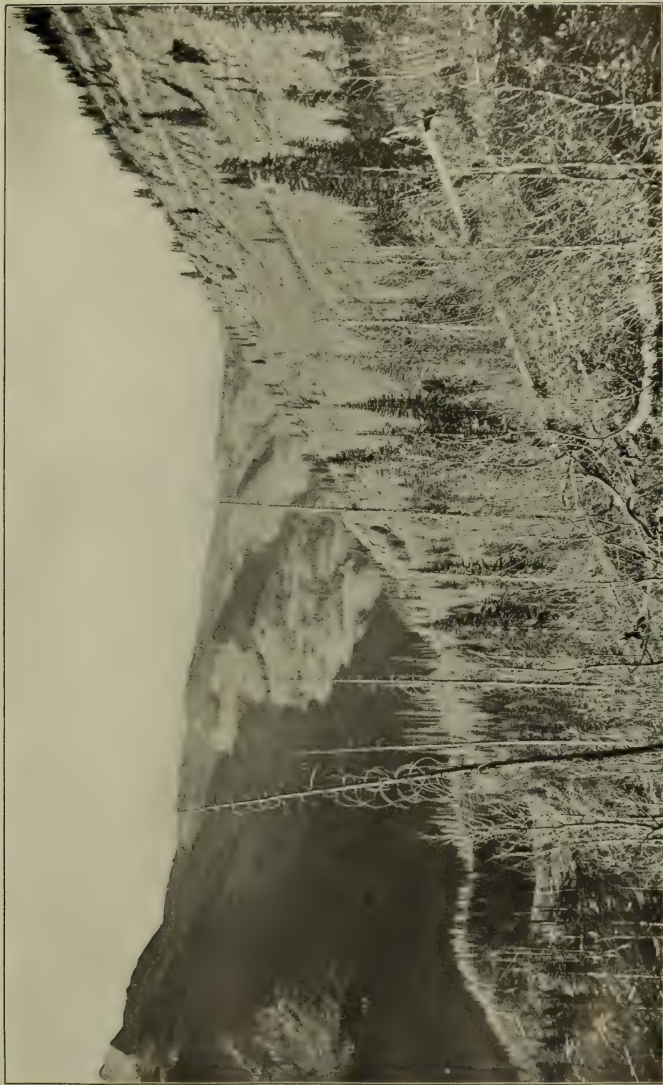
The physiographic relation of Newman Hill to Dolores Mountain is in some respects similar to that of C. H. C. Hill to Telescope Mountain, and the surface of Newman Hill is almost entirely of fragmental material. But it does not appear that landslides have played so important a rôle in producing this physiography as is the case on C. H. C. Hill. Yet the landslides of the western and southwestern slopes of Dolores Mountain must have sent their *débris* in avalanches down upon the lower slopes, and unmistakable evidence of such materials are seen in a knoll at 9,850 feet northeast of the old Enterprise tunnel, and in several patches of coarse *débris* along the upper part of the hill, especially on the slope to Deadwood Gulch.

REGION SOUTH OF BLACKHAWK PEAK.

The ridge leading east of south from Blackhawk Peak, just within the bounds of the special map, exhibits landslide phenomena which belong to the early stages of the movement. From the porphyry capping of the knoll near Blackhawk Peak southward to the porphyry hill having an elevation of 11,650+ feet, the rocks of the surface of this ridge are shattered and several blocks on each side have become detached and have slipped en masse or in avalanche down the slopes.

Several of the principal fractures on which slipping has occurred are now represented by trench ravines, the most distinct one being that shown by the map on the east side of the main ridge. Porphyry slide forms the crest east of this ravine from the level of 11,800 feet up to the hill above, while the ridge to the west is composed chiefly of much broken-up sedimentary rocks. Another line of fracture runs nearly north and south through the depression on the flat top of the ridge north of the porphyry mass at 11,650+ feet. This break is evidently back of a mass which has started to slip down the eastern slope into the basin beyond the map line.

From an elevation of 11,650 up to 11,900 feet on the broader part of the ridge under discussion the surface gives many indications that irregular blocks have begun to slip on each side of the ridge. There are several trenches crossing the ridge diagonally, some northeast-southwest and others northwest-southeast. Probably the notable amount of talus below the porphyry cliffs on the west has been caused by the fall and disintegration of one or more of the outer sections of



LANDSLIDE SINK ON C. H. C. HILL.

The sink lies at the base of ledges of rock in place on the northwest ridge of Telescope Mountain. Photograph by Cross.

the ridge. It is possible to map the porphyry sheet of this ridge in the general way expressed by the map, but broken-up portions of sedimentary beds are locally found along some of these cross trenches, which are supposed to belong to the strata normally above the sheet, but which may be due to marked irregularities in the upper surface of the porphyry, for several sheets of this region are known to have very uneven upper surfaces.

On the flat bench at the top of the porphyry are some open crevices, one notable one 3 or 4 feet wide, choked up by loose fragments to within a few feet of the surface. This seems to represent lateral displacement, doubtless on a layer of shaly sediments at or near the base of the intrusive porphyry sheet.

On both sides of the head of Aspen Creek, and in the gulch east of the ridge above described, are many masses of débris with sharp boundaries, which originated in landslides or more common avalanches from certain places in the cliffs above. Some of these masses form knolls or benches, grassed over or timber covered, and may represent landslide blocks.

DISCUSSION OF LANDSLIDE PHENOMENA.

Distribution of the landslides.—The landslides of special importance described in the foregoing pages are all located within a circular or oval area 4 or 5 miles in diameter, the center of which is close to the town of Rico. This area is geologically in the heart of the Rico uplift or dome, as now dissected by erosion, and this fact seems to have much significance. Landslides of minor importance have taken place within the Rico quadrangle beyond the center indicated, but they are hardly more frequent than in many districts of this part of Colorado and are not so closely connected with the phenomena of the Rico Mountains as to be of any value in a discussion of the latter.

While much the larger part of the surface within a circle 4 miles in diameter, with Rico at its center, exhibits distinct evidence of landslide action, there are areas which are notable exceptions to this rule. The most striking are the ridge ending in Sandstone Mountain and the northern part of Dolores Mountain. The bold cliffs of Sandstone Mountain are situated directly between the slide areas of Horse Gulch and C. H. C. Hill, and the rugged projecting ridges of Dolores Mountain might reasonably be expected to furnish large blocks under any general force exerted in this area.

As an examination of the map will show, the landslide areas bear no definite relation to the distribution of rock formations in the district. On the contrary, in respect to neither sedimentary horizons nor eruptive masses does there appear to be any significant limitation of the landslides.

Character of the landslides.—On reviewing the characteristics of the Rico landslides it appears that the landslide action has been very superficial. This fact appears most strikingly by comparing these slides with those of the Telluride quadrangle,¹ adjoining the Rico on the northeast. About Rico slide blocks 100 yards in diameter, within which the formations bear their normal relation to one another, are decidedly rare, while at the west base of the San Juan Mountains one such block extends for 2 or 3 miles. All the landslide areas about Rico are plainly made up of a number of small separate slips which were probably not contemporaneous. It is supposed that the slide block at the Puzzle mine is representative of those which cover the whole north slope of Darling Ridge. Some of the blocks may be larger than that at the Puzzle, but the latter illustrates the superficial extent of the blocks covering the slope above.

The statement that the landslide phenomena are superficial applies strictly only to the masses which have slipped out of place by gravitation. Doubtless many of the fractures of the rocks which permit the detachment of blocks extend downward far beyond the limits of the slipping masses, but only the outer shell of shattered rock can move under the force of gravity.

Aside from the fact of observation that the slide blocks are all small, the condition of the formations below the slide-covered surfaces affords further evidence of the superficial character of the phenomena. The most striking case in point is that of C. H. C. Hill. The topographic details of this hill, as illustrated in Pls. XV and XVI, indicate land-slip action over almost its entire surface, yet the ore deposits, both in vertical veins and in replacement masses, have been traced for considerable distances through shattered formations.

Relations to topography.—From the details regarding the various slide areas which have already been given, and from the illustrations of the plates, it is evident that the physiography of the Rico Mountains had acquired almost the detail it now exhibits when the landslides under discussion began. The only considerable modification of that physiography in the intervening time to the present has come directly from the landslides or indirectly through the rapid breaking down of the principal slide areas. The valley of the Dolores at the foot of C. H. C. Hill must have been of the exact type now seen above Burns. The stream bed of Horse Creek has plainly been interrupted by the Puzzle mine slide.

The primary condition for a landslide may be generally stated as a thoroughly fractured state of the rocks on slopes, permitting the force of gravity to cause the fall; and were all the rocks of a mountain district to be uniformly shattered the mountains of most precipitous and

¹ Geologic Atlas U. S., folio 57, Telluride, Colorado, 1899.



TREE SPLIT BY RECENT LANDSLIDE MOVEMENT, UPPER LIMIT OF C. H. C. HILL.

Photograph by G. W. Tower, jr.

irregular form would naturally experience the most extensive landslide action. But in the Rico district some of the most rugged mountains have undergone no visible degradation by landslips, even in the heart of the area most affected. Sandstone Mountain is the most striking instance of this immunity.

In harmony with this negative evidence is the positive fact that the ridges most thoroughly affected by the phenomena must have had comparatively gentle slopes at the beginning of the landslide epoch, due allowance being made for the obliteration of their boldest detail by subsequent events.

Relations to other Pleistocene phenomena.—The ordinary processes of degradation operative in the high mountain regions of Colorado have of course been active in the Rico Mountains during the long epoch of landslide action, and it scarcely need be pointed out that all the destructive agencies must have been especially effective within the landslide areas. The shattered landslip blocks themselves have been in high degree vulnerable to the attacks of solvent waters, frost, etc., and have in many cases rapidly disintegrated. The whole slope of Darling Ridge, as of other landslide areas, is practically without surface drainage channels, so permeable is the mass beneath to the rain that falls upon it and to the snow water.

One effect of this saturation by circulating water has been to keep the fracture lines of attrition matter and many layers of crushed sandy shale in a soft condition, favorable to the slipping of more or less extensive masses whenever the support is weakened sufficiently. Secondary slides of this sort must have been frequent ever since the original shattering of the formations, and they are still taking place.

The more exposed and isolated landslide blocks, if prevented from further slipping en masse, break up gradually, and a talus slope or an avalanche track often denotes the course of the more rapid disintegration. The destruction of the blocks on the south slope of Landslip Mountain is clearly illustrated by Pl. XX, and the result of long-continued action in an area of extensive fracturing may be seen in the ridge extending from Expectation Mountain shown in Pl. XIX.

Age of the landslides.—The epoch of the Rico landslides extends from their beginning to the present day. From the great number of the slides in this limited region it must be assumed that they are due to some very unusual force shattering the rocks to a remarkable degree, and it is most natural to assume, further, that that force was catastrophic and principally exerted at one time—the beginning of the landslide epoch. It is therefore of prime interest to ascertain when these slides began.

The evidence afforded by the relation of the slides to the topography of the district has been given. The principal changes in the topography since the landslides began have been caused by the slides themselves. There has been practically no erosion in the Dolores Valley or in the

more evenly graded reaches of its local tributaries in the landslide epoch.

Of all the phenomena of Pleistocene age in this region there is none affording definite proof as to the remoteness of the time at which the fracturing of the formations took place. All the distinct alluvial formations, as flood plains, and the fans or aprons at the mouths of streams tributary to the Dolores, are referable to activities during the landslide epoch. Even the glacial deposits seem to afford little evidence as to the age of the first landslides. The main traces of glacial deposits are in the eastern portion of the Rico Mountains and at places where landslides have not occurred. And the gravel deposits, which seem to be of glacial origin, have in most cases been more or less rearranged, so that little weight can be given to conclusions drawn from their present position. The landslide period was apparently contemporaneous with the glaciation, or nearly so.

The slides are definitely earlier than the forests growing upon many of them, and these growths are comparable to the common forest growth of the high mountain areas of the State.

Relation to faults. As the landslides occur in the heart of the Rico uplift they are coextensive in a general way with the principal faulting in the rocks of the dome, and one of the most obvious hypotheses as to the origin of the landslides is based upon the assumption that the two phenomena are genetically connected. On analysis of the observed facts it appears that several of the principal landslide areas are traversed by important faults, but that, on the other hand, some of the most complex fault zones or tracts do not exhibit landslide action.

The faults of C. H. C. Hill seem at first glance to be parallel with the trenches of the principal landslides, running northwest-southeast. The strong fault veins of the west side of the Dolores, below Marguerite Gulch, are in line with several crossing the ridge leading from Telescope Mountain to Nigger Baby Hill, and through the shattered intermediate ground of C. H. C. Hill run a number of veins in the same general course. These are invariably greatly broken up, so that they are now zones of loose fragmental material, as strikingly shown by the "big fissure," the quartz vein exploited in the Pigeon, Logan, and other claims, which lies below the strong trench of the view in Pl. XV. As has been pointed out, the northeast cliff bounding C. H. C. Hill seems to be parallel to a system of fault veins known in that area, and the landslides adjacent to the cliffs appear to represent great bands of rock between some of the fissures of that system.

The cross faults, of which three are shown on the map, may have had some influence in subdividing the zones of the main system.

The ridge from Expectation Mountain to the mouth of Burnett Gulch is probably traversed by the Deadwood and Spruce Gulch faults, but their presence has not been determined, nor has any other fault been proved to exist in that area.

It is not unlikely that several faults cross the Dolores from the east



VIEW LOOKING DOWN THE LANDSLIDE RIDGE SOUTHEAST OF EXPECTATION MOUNTAIN.

Shows the landslide topography at the stage when it has become almost obliterated by denigration of the shattered blocks. In the distance on the right are the La Plata Mountains, and in the center is the crest line of Indian Trail Ridge. Photograph by Cross.

into the landslide area of Horse Gulch and Darling Ridge, yet no indications connect these fault courses with fracturing of the landslide period. The same is true of the north side of Horse Creek.

The small landslide area on the ridge south of Blackhawk Peak is in the line of the Blackhawk fault, and some of the trenches have the general course of that fault, but as the actual dislocations of the fault have not been traced as far as the slide, it is not possible to show any dependent relation between those fractures of the rocks.

As will appear in the discussion of Newman Hill, there is a great deal of recent fissuring and movement clearly proved in the mine developments, but the connection between that movement and the landslide of adjacent areas is a matter of inference. From the recent age of the landslides it becomes plain that if there is any causal connection between them and the older faults of the district it comes through lines of weakness in the rocks along those faults, of which the much later forces made use. The question is further discussed under the next heading.

Origin of the landslides.—The immediate cause of the Rico landslides is manifestly the very unusually shattered condition of the rock formations on steep slopes, and the discussion of origin must be directed to the seat and nature of the force to which the intense shattering is due. The evidence concerning this force contained in the observations which have been recorded may be summarized as follows:

1. The principal landslides are confined to a small circular area in the heart of the Rico uplift, but do not cover all of that area.
2. The slides are more recent than the topographic details of the mountains and valleys, excepting only some recent and minor features.
3. The shattering of the rocks varies locally in degree.
4. The shattering is independent of lithological character and structural attitude of the formation, and there is nothing in either of these conditions especially favorable to landslides.
5. The principal landslide slopes are in the courses of many known faults, but several intensely faulted areas of rugged topography do not exhibit landslides.
6. Many fault veins seem to have been opened again by the shock producing the shattering of the formations.
7. The shattering extends below the surface zone of actual sliding, and to unknown depths.

The consideration of all observed facts leads to the comprehensive statement that in geologically very recent time a part of the central portion of the Rico Mountains suffered a severe shock, shattering the rocks at the surface and to unknown depths. As a result of this shattering many landslides have occurred where other conditions were favorable. This shock must have had its source in greater or less depth, and may be referred to as an earthquake shock.

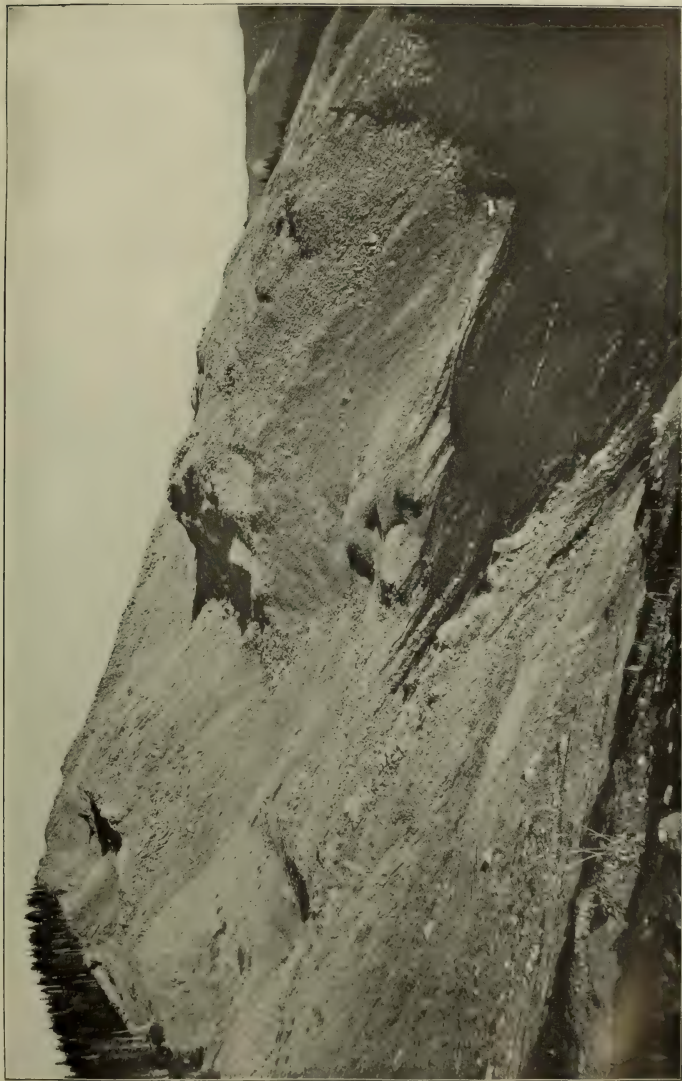
Two important sources of earthquake shock are specially recognized, viz, that originating in the relief of tension arising from structural movements of the earth's crust, and that connected with volcanic phenomena. The Rico Mountains represent a center of upheaval and intense faulting, and of igneous intrusions of a nature not strictly volcanic. It seems natural to suppose that seismic disturbances must have taken place at the surface of the Rico dome during the periods of faulting and during the intrusion at least of the monzonite magma in the channels represented by the stocks of to-day. But those disturbances took place at so distant an epoch that the connection of the shocks now under discussion with either of them is not plausible.

A hypothesis to explain the earthquake shock of recent time in the Rico Mountains must satisfy a number of conditions of observation, and the most difficult facts to meet seem those found to hold true in regard to the Darling Ridge locality. Here is a considerable area containing nearly horizontal rock formations, penetrated by sheets and one or more stocks of monzonite. The topography is not specially rugged, faulting is certainly much subordinate in extent to that of adjacent areas like Silver Gulch, yet the most profound and complete fracturing seems to have occurred in this area.

It is a matter of common belief to-day among structural geologists that movement is still in progress on many old fault lines which continue to be lines of weakness. The recent movement is thought to be gradual, and if the existing tension finds sudden relief by dislocation, even of minor extent, it is supposed that perceptible or even violent earthquake shock may be experienced at the surface. These ideas have been applied notably to the explanation of the great Charleston earthquake of 1886.

If, now, the recent shattering of the rocks in the Rico district be assumed to be the result of faulting, an adjustment of the rocks under stresses still existing at this center of uplift, the opening of old faults may be explained, and the great shattering on new and irregular fractures may be regarded as a natural distribution of the shock in the superficial zone, where resistance to fracture is less than in depth. But while little positive evidence appears to oppose this hypothesis, it must be considered remarkable that Silver Gulch, the locality of most intense and deep-seated faulting, judging from surface dislocation, has not been the scene of landslides. On the other hand, the locality where the shattering force seems to have vented itself in greatest violence is certainly not one of the principal fault areas of the region, although some faulting is to be considered probable.

The hypothesis that the supposed Rico earthquake originated in volcanic forces seems to the writer to be better adapted to the requirements of the case than that of recent faulting. The ultimate cause of volcanic earthquake shock need not be discussed here, for it is one of the most commonly recognized facts of observation that such phenom-



SOUTH FACE OF LANDSLIP MOUNTAIN.

Shows several landslide blocks many of porphyry, in process of disintegration by atmospheric agencies. Photograph by Cross.

ena are characteristic of volcanic regions. Rico lies almost immediately adjacent to the San Juan volcanic area, one of the most extensive in the United States, and it is certainly reasonable to assume that of the earthquakes doubtless experienced in this region some were especially felt about Rico, even if there was nothing in the conditions beneath the Rico uplift to produce local shocks at that center of igneous activity. Given a violent disturbance of volcanic origin beneath the Rico dome, it may be assumed that its transmission to the surface would be influenced by lines of weakness, such as existing faults, and coexistent earth stresses might determine which fissures out of a complicated system would be most affected. Under this hypothesis the reopening of fault veins is a result and not the cause of the shock by which many other new fractures were made in the rocks.

The volcanic hypothesis seems to furnish an explanation of the intense fracturing of the rocks on Darling Ridge. It is conceivable that the monzonite stock, penetrating the heterogeneous series of sedimentary rocks as a massive and continuous body extending far toward the supposed local seat of volcanic energy, would serve to transmit to the surface in relatively undiminished force the shock assumed by this hypothesis. It is certainly true that the impression as to the violence of the force which has been here exerted has been far stronger on the writer's mind when among the huge blocks of monzonite on the summit of Darling Ridge, and well within the borders of the stock, than when at any other locality in the Rico Mountains.

The gigantic landslides of the Telluride quadrangle have also been ascribed by the writer to earthquake shock.¹ But there is so great a difference between these slides and those of the Rico Mountains that different causes might well be assigned. The Telluride landslides are enormous. The rocks affected are mainly a great volcanic series resting on soft Cretaceous shales—a lithological element of much importance lacking in the Rico Mountains—and they have occurred upon the bold front of the San Juan Mountains. Faulting is there very subordinate in importance, and that the dislocation of these huge masses should be referred to earthquake shock of volcanic origin is natural under the circumstances. The relation of the Telluride phenomena to those of Rico is significant mainly in that they have occurred in the same general period of recent time; it is but 14 miles from Rico to the great landslide area adjacent to Trout Lake, and if the landslides of the Telluride quadrangle were due to volcanic shock it seems inevitable that that disturbance must have been strongly felt in Rico. It is a possibility that the fractures of the rocks in the two localities leading to landslides were primarily due to the same great disturbance, transmitted to the surface in the Rico district under local conditions already discussed.

¹ Telluride folio

CHAPTER VI.

EROSION OF THE RICO DOME AND RECENT GEOLOGIC HISTORY.

By ARTHUR COE SPENCER.

EROSION OF THE DOME.

General statement.—Of all the events of Tertiary time up to the intrusion of the igneous masses and the uplift of the dome we have no record in the phenomena presented at Rico. In the adjacent country to the north and east, however, we have evidence that the Mesozoic was followed by extensive erosion which was continued for a sufficient length of time for the removal of the entire sedimentary section from the central portion of the San Juan region. We have also in the San Miguel formation the evidence of the existence of a large lake in the later part of this period of erosion, and in the breccias of the overlying San Juan formation a witness to the beginning of volcanic deposition, which was continued until the region was covered to a depth of several thousand feet with pyroclastic and massive extruded rocks. Doubtless, as pointed out in the Telluride folio,¹ this upbuilding was accompanied by vigorous erosion, but until the cessation of the former the latter was probably in abeyance. Now, the early Tertiary history at Rico must have been that of the San Juan at large, but the amount of post-Mesozoic erosion is not known, nor is the probable thickness of the volcanic accumulations which covered the site of the present mountains to be estimated; but here they were doubtless undergoing erosion during deposition, and upon the land surface formed by them the drainage system was being developed from which the present streams have inherited many of their main features.

At the inception of the Rico dome the extruded rocks which covered the San Juan country were being attacked upon all sides by streams whose positions were probably determined by the distribution of the volcanic materials. So long as eruption continued the stream courses were constantly liable to alteration by lava flows, but with the cessation of volcanic activity each stream would maintain the course it then held,

¹ Geologic Atlas U. S., folio 57, Telluride, Colo., 1899, p. 1, Tertiary history.

deepening its channel and sapping at its head to extend its canyon into the central mountainous region. It seems probable that the Dolores River had assumed its present course previous to the formation of the Rico dome, since, supposing that the surface at the time the dome was formed was sufficiently smooth for the development of consequent drainage upon its slopes, it is difficult to understand how one of the radial streams thus resulting could have gained so distinct an advantage over the others that it would finally cause their complete diversion. This objection is particularly applicable at Rico, because the relations of hard and soft rocks in the region to the north of the dome are such that diversion of the present headwaters of the eastern branch of the Dolores must have been accomplished by the western branch of that river long before any stream originating on the southern slope of the Rico dome could have extended its course northward across the opposing strata on the north side of the dome structure.

As stated in a preceding chapter, it is believed that the Rico deformation accompanied a general regional uplift. If this idea is correct it follows that while erosion has been continuous in the central San Juan since the beginning of volcanic deposition an epoch of increased activity in erosion must have followed this elevation, even if the streams had previously found permanent courses.

The actual amount of erosion since the Rico uplift can not be estimated, since its effects are not separable from those of the epoch preceding. It may be surmised, however, that the volcanic rocks had not been removed entirely and that sediments above those now exposed may have been present at least well up into the Mancos shale at the time of uplift.

The epoch of erosion since the latest important uplift of which we have any record in the Rico region may be divided into three stages, which are applicable to the San Juan at large as well as at Rico. During the first stage the greater amount of erosion was accomplished and the topography had reached practically its present form. During the second there was an accumulation of ice with the formation of local glaciers and the production of such forms of erosion as glacial cirques and U-shaped valleys. To the same part of the epoch belong the landslide phenomena, though their exact age relations are not to be made out at Rico. In the Telluride region, however, there is some evidence for believing that the landslides had taken place before the maximum advance of the ice. The landslides are so important a feature of the geology of the Rico region that they have been made the subject of special study by Mr. Cross, who describes and discusses them in a separate chapter. The third or present stage dates from the retreat of the ice, which is geologically very recent, as shown by the small amount of erosion that has been since accomplished.

The correlation of the latest epoch of erosion with the accepted divi-

sions of geological time is a question which can not be solved at Rico. If the age of the local uplift be accepted as Tertiary, the first stage must be considered as also belonging to that period, in part, at least. If, on the other hand, the uplift could be considered as closing the Tertiary, all subsequent events would belong to the Pleistocene. In favor of the former conclusion we have the ore-bearing veins, the deposition of which must have required a long time, but which are manifestly later than the deformation.

Pre-Glacial erosion.—It has been shown that erosion in the Rico region has probably been continuous since early Tertiary time, and that there is no way of determining the relative amount of degradation in the earlier and later epochs of the period, or of separating the latest Tertiary erosion from that of Pleistocene time. Whether the Dolores was flowing in a shallow valley or a deep canyon previous to the domal uplift at Rico can not be surmised, but before the completion of the structure the stream had doubtless cut a deep trench well down toward the base of the volcanic rocks which are supposed to have covered the region, and possibly into the Mesozoic sedimentary rocks, upon which they probably rested. This erosion belonged to the epoch of deformation. It was succeeded by continued erosion of the present epoch as arbitrarily limited by the completion of the distinct uplift. At this early stage of erosion the adjacent streams must have had practically their present positions, though possibly they have since enlarged their headwater drainage on the flanks of the Rico Mountains at the expense of the neighboring tributaries of the Dolores. This would naturally follow from the interior streams having to encounter rock more difficult of corrasion than the outside streams, and seems to be indicated by the greater length of the exterior tributaries.

With the downward cutting, which has since continued, there has doubtless been concomitant elevation, but of this there is no evidence in the immediate vicinity of Rico, though within the Rico quadrangle, some 10 miles or so to the south, there are gravel beds about 400 feet above the present valley floor, showing the former position of the stream bed and indicating an uplift since their deposition. The effect of erosion within the mountains has been as though the river had cut its way at once to the present position and then side streams and gullies had completed the grading of the slopes. It is believed, however, that several distinct uplifts have occurred, but the pauses between them left no records because of the fact that the river was cutting its channel and not at any time widening its valley, so that the valley was successively deepened, and under conditions of heavy precipitation the slopes of the valley walls were gradually reduced without the production of terraces.

The topography is always in close sympathy with the geology, and

almost every feature of the landscape not directly referable to the phenomena of the landslides is the result of differential erosion. The softer rocks have been carved away, leaving the more indurate as cliffs or steep slopes between more gentle acclivities and determining the positions of the main mountain masses. The rocks which have been sufficiently massive to form mountain caps are mostly intruded porphyries, though the La Plata sandstone always rises as a knob above the general level of the adjacent ridges. Of the few high peaks capped by other sediments than La Plata, Telescope, and Sandstone mountains are the only ones not protected by a very massive sheet of porphyry lying within 100 to 200 feet of the top. The former is capped by a heavy conglomerate of the Dolores and is not entirely without protecting porphyries in its upper part, but the latter is composed of the Dolores sandstones entirely, though it is in reality a ridge leading to the much higher Elliott Peak, which is doubly protected from erosion by the La Plata sandstone and an overlying porphyry mass, so that the preservation of Sandstone Mountain may be considered as incident to the presence of the more prominent peak.

The monzonite stock upon the west side of the river has been sufficiently resistant to form a ridge both south of Aztec Gulch and in the main divide south of Horse Gulch, though in neither place does it reach to as high an elevation as the porphyries of the adjacent peaks.

The distribution of the laccolithic porphyry masses in the sediments has been discussed in a previous chapter. Their presence in the upper part of the Dolores formation has determined the zonal grouping of the principal mountain peaks about the center of the dome structure. In fact, it is to these porphyries that the Rico Mountains owe their existence. Had they not been encountered by the streams, the latter, in dissecting, would have given to the dome a molding scarcely different from that which they have impressed upon the adjacent areas of sedimentary rocks; the concentric outcrops of the harder beds would be expressed in knolls or curving ridges, but the general elevation would have been much less than at present.

The positions of the side streams of the mountains have probably persisted from a very early date, and they are in no way dependent upon the distribution of the rocks that they now cut across, though they may have been located by the occurrence of porphyry masses in the central part of the area at horizons which have now suffered complete erosion. Both the main stream and its tributaries had reached practically their present position before the change in climatic conditions filled the upper valleys with ice. The dissection of the uplifted rocks was almost as complete as at present; the entire sedimentary section and its accompanying intrusions had been cut through and the Algonkian rocks had been exposed. Measured by its geological effects, the time which has subsequently elapsed is relatively very short; land-

slides have locally modified the surface: the ice streams remolded the valleys slightly, scouring and depositing; flood waters in the main valley deposited gravel terraces, which have since been largely removed. But all of this is very unimportant in comparison with the great erosion subsequent to deformation and previous to glaciation.

GLACIATION OF THE RICO MOUNTAINS.

Forms of evidence.—Evidence of the former existence of local glaciers in the Rico Mountains was to be expected from a knowledge that the higher portions of the San Juan region had been at one time practically covered by an ice sheet. The facts leading to this conclusion have yet to be correlated before any general discussion can be attempted, but many of the topographic features illustrated on the maps of the Geological Survey are sufficient to indicate the former existence of glacial ice in the high mountainous region of the San Juan.

The amphitheatres usually containing small lakelets, in which the valleys have their heads, are to the student of glaciers and their work *prima facie* evidence of ice accumulation. Moreover, in the region there are many valleys with the U-shaped cross section; there are also morainal accumulations, scored and scratched rock surfaces, and even the characteristic form of glacial erosion known as *roches moutonnées*, all of which serve to prove the general fact of glaciation.¹

At Rico the record of the ice invasion is seen in certain topographic forms, in rock scoring, and in accumulations of *débris*, but none of these are strikingly prominent or characteristic, from which it seems that because of their somewhat lower altitude and their isolation the Rico Mountains were not so completely dominated by the ice as were the higher mountains adjacent. They formed a local center of accumulation, and though the greater number of the basins at Rico were probably piled high with snow there were only two or three cases in which the accumulation became sufficiently deep for the consolidation of the snow into true glacial ice.

Topographic evidence.—The topographic features of the Rico Mountains are disappointing as criteria for the determination whether or not a given gulch has supported an ice stream. Only a single basin of all those represented could be definitely recognized as a glacial cirque from an inspection of the topographic map. This one, which lies just east of Allyn Gulch, is quite typical of the amphitheater as a glacial form, but is somewhat obscured by *débris* from the surrounding walls. Three other somewhat cirque-like basins draining into Horse Gulch occur on the southern side of Sockrider Peak. Possibly the lack of characteristic form in some instances may be due to

¹ On the glacial phenomena of this region see the Telluride folio and a paper by George H. Stone, entitled *The Las Animas Glacier*; Jour. Geol., Vol. I, 1893, pp. 471-475.

accumulations of talus and slide rock, but in the main it seems that amphitheaters have never been excavated even at the head of valleys otherwise known to have been filled with ice.

A second topographic feature which is often characteristic of glaciated areas is seen in the distributed drainage in the main head of Silver Creek, which lies within our area just to the east of Blackhawk Peak, whence the stream, after running northeastward for a short distance, turns into its westerly course east of the mapped area. Here there is a broad slope of porphyry from which the ice has swept most of the surface débris, and over this slope the waters flow in small converging but independent rivulets rather than in a single stream gathered into a central channel.

The valley of Silver Creek is broader at the bottom than the ordinary gulch eroded by running water, and it is believed that the more open valley is to be explained by the former presence of an ice stream, since such a broadening of water-cut valleys is known to be usually characteristic of glacial action. Likewise in the case of Horse Gulch the same origin may be suggested, though here it is evident that landslides have entered into the development of the valley cross section, so that the glacial origin is involved in more doubt. In none of the other gulches is there suggestion of any erosion except that of running water.

Evidence of glacial action, based upon scored rock surfaces, is meager. A few small surfaces of polished and striated rock were observed near the head of Bull Creek, west of Calico Peak. Small patches of smoothed and striated sandstone were noted about 300 feet above the river, just south of Marguerite Draw and near the bed of Deadwood Gulch, at an elevation of about 10,150 feet. Also limestone exposures just above the falls in Deadwood Gulch (elevation 9,800 feet) are planed and scored. Elsewhere no distinct markings have been observed, except in the head of Silver Creek, where the sloping floor of porphyry shows some scoring and scratching besides the general cleaned-up effect due to the removal of surface débris through the action of moving ice and snow. The general absence of such features is not, however, to be wondered at, since the character of most of the rocks in the valley is not suited to the preservation of fresh surfaces.

Glacial débris.—Passing now to the accumulations of glacial débris, it may be said that none of the deposits show the ordinary topographic forms of moraines or kindred features, but occur merely as gravels or loose rock fragments in such positions that they can hardly be accounted for as ordinary terrace gravels. The character of these deposits is, for the most part, typical of glacial materials which have not suffered long transportation. Angular or subangular fragments of the various rocks within the drainage of the former ice stream are thrown together in the utmost confusion, rounded pebbles being of

unusual occurrence. In the mapping of the surface materials it has been found impossible to discriminate all the deposits according to their origin, so that the glacial gravels are not represented as distinct, and, indeed, the different forms of loose *débris* intergrade in such a way that they are often indistinguishable on the ground. Accumulations found along the south side of Newman Hill, next to Deadwood Gulch, have been attributed to an ice stream which occupied the upper part of the gulch. Those near the mouth of Allyn Gulch are to be attributed to a similar ice stream and were probably deposited at a time when the stream in Allyn Gulch did not join that of the main valley. The heavy gravels which occur in the northern part of Newman Hill contain much waterworn material, which may have been deposited from a stream flowing along the south side of the Silver Creek glacier when it extended as far as the river, completely closing the channel of the tributary to the waters of Allyn Gulch. Doubtless avalanche material from the slopes of Dolores Peak has given rise to much of the covering of Newman Hill, and it is also certain that there have been landslides, but the presence of waterworn pebbles requires some such explanation as that given above.

The rounded ridge which marks the entrance to the valley of Silver Creek may also be mentioned, since it has an external appearance similar to kames or eskers, but it is really composed of sedimentary rocks and intrusive porphyry and is merely capped by gravels. It is consequently a remnant of erosion rather than a constructed form.

In Papoose Gulch and on the eastern slope of Mount Elliott there are surficial deposits which are related to the glacial deposits in origin, and are probably in part of the same age. They consist of heterogeneous masses of rock fragments of various size filling the gulch or forming a ridge, as in the last locality mentioned. These are supposed to have been formed by materials which have accumulated at the base or along the sides of great snow banks which filled the basin above, but never attained the thickness requisite for the formation of true ice. Similar accumulations of recent origin are frequently seen in mountainous regions of heavy snowfall. They are often to be noted in the San Juan region, but these particular occurrences possibly date back to the time of the ice invasion.

Coarse gravel beds, which from their position suggest a considerable former extent of such materials, were observed by Mr. Cross on the slope north of the monzonite arm that comes down almost to the houses in Piedmont. At an elevation of 9,500 feet, or about 700 feet above the river, an excavation in the wooded surface reveals a mass of very round boulders lying in fine gravel. Among the rocks represented were blue limestone, greenish sandstone, and vein quartz. The boulders are very unlike the angular fragments which are sparingly

scattered about on the surface. These angular blocks, often 3 feet or more in diameter, seem to have come from up the river, for red Dolores sandstone is common among them. Boulder gravels have also been exposed in prospects near the line of the Calumet vein and about 300 feet above the river. So much of the surface south of Aztec Gulch is timbered, with no solid rock outcrops, that it seems possible that there may be much of this gravel in the vicinity.

On the slope below the tufa bench south of Sulphur Creek, at about 300 feet above the river, there are several patches of coarse gravel beds. Among the fragments noticed here was one block, nearly 3 feet in diameter, of the peculiar hornblendic porphyry known only in dikes in the Algonkian schists above Rico.

These two occurrences of heavy gravels indicate a much greater amount of probable glacial débris in the Dolores Valley than is to be inferred from any other evidence observed. Knowledge of these gravels is clearly too meager to warrant generalizations upon them at present.

Still another class of deposits which may be tentatively referred to the time of the ice invasion is seen in the gravel terrace upon which the town of Rico is partly built, and the similar and probably corresponding gravels which occur on the slight bench about 40 or 50 feet above the river bed upon the west side north of the mouth of Sulphur Creek. The gravels are best exposed in the cutting for the roadway to the railroad station, but are known to form the edge of the terrace for nearly half a mile toward the south. It seems probable that these gravels represent the level of the river valley at some particular period of glaciation.

Collectively the phenomena cited in the foregoing paragraphs are believed to warrant the conclusion that true glacial streams at one time occupied the valley of Silver Creek and its tributaries and that of Deadwood Gulch, and that in the upper part of Horse Gulch there were important accumulations of ice; which may or may not have reached into the lower part of the valley. Deposits of a morainal character not hitherto mentioned are known to occur beyond the limits of our map in the northern tributaries of Scotch Creek, and these indicate that there were short glaciers on the southeast side of the eastern part of the mountain group, but beyond this we have no further proof of individual ice streams in the Rico Mountains. Others may have existed, but their marks have been obliterated by surface materials of another origin or by the erosion which has taken place since their dissolution by climatic conditions. All the facts available point to the very local nature of the glaciation of the Rico Mountains and to the short duration of glacial conditions.

RECENT GEOLOGIC HISTORY.

Many of the features of post-Glacial geology at Rico are inseparable in origin from similar features of Glacial and earlier time, since in those parts of the area that were not covered by the ice similar processes of general erosion and of local deposition were active throughout the Glacial stage. For this reason, in classing the following phenomena as recent, there is no intention of limiting their age to the post-Glacial, but rather to indicate that the conditions which have produced them have continued down to the present time. The recent phenomena of the Rico region may be classed as those of erosion and those of deposition. The latter will include landslides, talus and avalanche materials, river gravels, and spring deposits.

Post-Glacial erosion.—If the gravels observed by Mr. Cross at an elevation of 700 feet above the river on the northern edge of the monzonite are really of glacial origin, they indicate a much greater accumulation of such débris in the Dolores Valley than would be suggested by any other occurrences. But even if they are glacial, the work of the river seems to have been largely the removal of the gravels, with little cutting into the underlying rock. In Deadwood and Allyn gulches the streams have cut down through the unconsolidated gravels of glacial origin, but this is a task which they could have easily accomplished in a short time. Similar indications of the small effect of post-Glacial bed-rock erosion are seen in Silver Creek, where the stream has locally excavated narrow canyons in the wider valley of glacial origin, but these canyons have in no instance exposed the bed rock to a depth of more than possibly 20 feet, and in many places the stream is working upon débris of very recent origin, which has been thrown into its channel from the side gulches and ravines. All the evidence serves to point to the recency of the glacial occupation and to the small amount of erosion which has since ensued. The present topography is in no essential feature different from what it was previous to the accumulation of the ice. Before that the streams had found their present courses and had practically assumed their present grades. Greatly in excess of any topographic changes due to erosion are those attributable to the constructional features which are discussed in the following paragraphs.

Varieties of surface deposits.—The surface deposits at Rico are of very diverse character and origin, and, as has been seen in the discussion of the glacial gravels, they are not easily separable as to origin. They are very troublesome to the geologist, since they cover the central part of the region to such an extent that it has been found impossible to work out the geology of the solid rocks underlying. Consequently it is necessary to represent them on the map, and for this purpose five distinct patterns have been used to distinguish (1) areas

made up principally of landslide material; (2) valley gravels; (3) alluvial cones; (4) spring deposits; (5) materials of other origin, such as avalanche, glacial, and surface wash.

Landslides.—The most important surface deposits in the Rico Mountain are of landslide origin. One such slide has materially altered the grade of the Dolores River north of Rico, others have changed the profile of Horse Gulch, while still others lend their characteristic pseudo-glacial topography to the mountain slopes in several places. This feature of the Rico region has been specially studied by Mr. Cross, and its description and discussion are given a separate chapter in this report.

Talus.—Accumulations from the wasting of cliffs are related in origin to landslides, but are composed of many small blocks loosened by frost action or by heavy rains, whereas landslides, though they may eventually become very much broken, are at first essentially large masses. Talus forms are of frequent occurrence at Rico, and while in many cases, especially in the lower parts of the mountains, their even slopes are covered with vegetation, in other cases they are entirely bare and then suggest the manner in which they were formed, namely, by the rolling and sliding of loose rock fragments under the action of gravity. They are well illustrated in several of the accompanying plates, particularly in Pl. VI (p. 28), showing the steep talus at the base of the Sandstone Mountain cliffs, and in the view of Calico Peak (Pl. VII, p. 32) and that of Blackhawk and Dolores peaks from the north (Pl. IV, p. 24). The long talus streams upon the west slope of Nigger Baby Hill are largely derived from the mines which are situated at their heads, but the whole adjacent slope is covered by natural talus or wash through which very few outcrops appear.

Related to talus are the materials dislodged by avalanches and deposited where their force is spent. Much of the loose material upon Newman and C. H. C. hills has been brought down in this way, and the paths which have been cut through the timber upon the western slope of Dolores Mountain may be made out from the photograph of this slope (Pl. III, p. 22). Other ravines than these, which have been the tracks of snowslides, may be seen at various places. Some of the best marked are on the south side of Burnett Creek, upon the flank of Landslip Mountain.

The deposits of Papoose Gulch and in the head of Marguerite Draw west of Mount Elliott have been mentioned in discussing the glacial phenomena, where they are considered as connected with former great snow banks. Probably this is, in part at least, their true origin, but avalanches may have been also concerned in their formation.

Surface wash.—In regions where the agents of erosion have been as active as at Rico rocks do not decay in situ by surface weathering, and consequently residual soils, such as cover the rocks in many low-

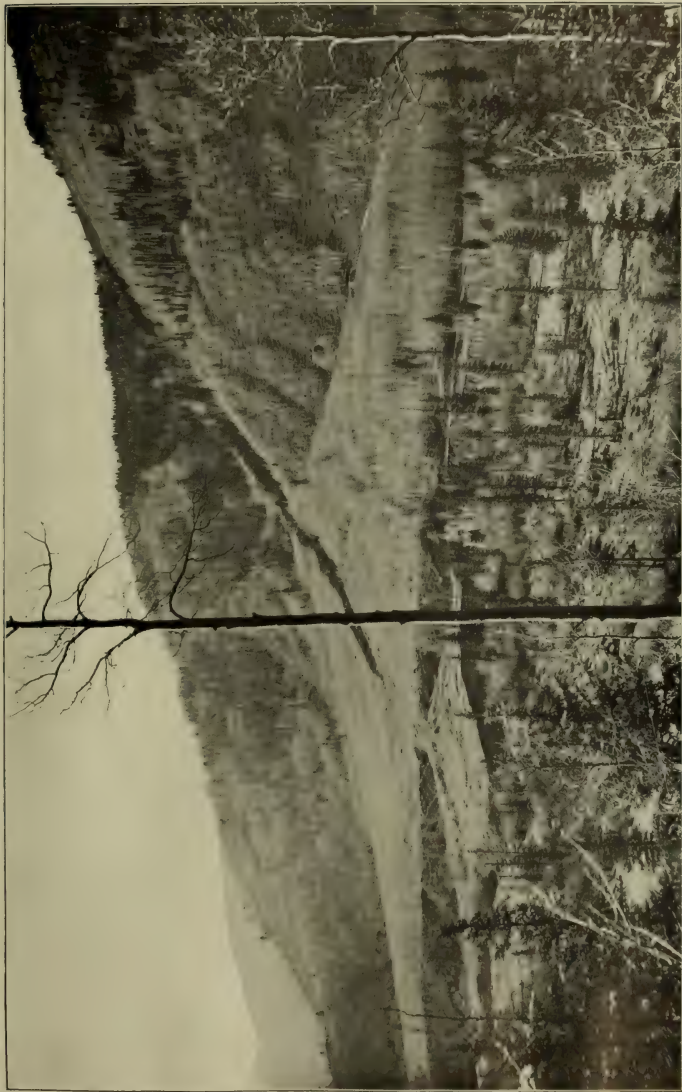
lying regions, do not accumulate. Surface wash is composed almost entirely of fragments derived from the higher slopes of the mountains, or from the disintegration of landslides which, gradually moving toward the valleys under such effective aids to gravity as snow, rain, and frost, have been spread in varying thickness over extensive slopes, hiding the underlying formations as completely as have the more massive surface deposits. As may be inferred from such an origin, the materials of the surface wash are as a rule more completely pulverized than the other forms of surface deposits.

As in the case of all the surface deposits, the representation of surface wash on the map is generalized and the indicated boundaries are to be taken as approximate. The symbol under which they are included is intended to apply to all areas not referable to the three classes of landslides, valley deposits, and alluvial fans. It thus comprises the materials of mixed origin covering Newman Hill and the opposite slope west of the river.

Valley deposits.—The valley deposits of the Rico region comprise the gravels of the present flood plain of the river. They consequently occur in a band across the area and bordering the river, but interrupted above Horse Gulch by the great landslide at the base of C. H. C. Hill. This mass of rock which has been projected into the valley has pushed the stream against the western bank of the canyon, where it is now cutting in the solid rocks of the lower Hermosa. As may be seen by referring to the topographic map, it has interfered with the natural grade of the river, which is now abnormally steep adjacent to the slide block upon the lower side and as notably low in the reach upstream from it. The landslide at first formed a dam across the river, causing slack water for perhaps a mile and a half upstream. From the even spacing of the contours below the dam it is believed that the original stream bed at the lower end of the Burns meadow is approximately 75 feet below the present position of the river, the same figure representing the thickness of the materials deposited by the river at this place. If the same spacing which is noted below the landslide were continued upstream the 9,050-foot contour would have approximately its present position, so that it may be taken to represent about the upper limit of the effect of the landslide in changing the stream grade. From the dam to the present crossing of this contour the distance is slightly in excess of 1 mile, and the fall of the stream is not more than 25 feet, or less than one-fourth the normal fall for this distance. The northern edge of the landslide block and the flat above it are shown in Pl. XVI (p. 142).

The materials of the valley deposits are coarse gravels and sands which the river has derived from its tributaries and which it has rolled along and distributed within its immediate valley.

Alluvial fans.—The steeper gulches which open directly into the



ALLUVIAL FAN AT THE MOUTH OF AZTEC GULCH.

Shows the scarp across the end of the fan caused by the cutting of the Dolores River and the secondary fan of modern formation to which the present drainage channel leads. Photograph by Cross.

Dolores Valley have all afforded detritus faster than the river has been able to carry it off, so that the débris brought down by the side streams has accumulated in conical banks at the mouths of the gulches. Such accumulations are commonly known as alluvial fans. They are a characteristic feature of the union of streams of steep grade with those of low declivity, since the transporting power of the steeper streams is suddenly diminished when their grade is reduced. The side streams at Rico do not at ordinary times carry any appreciable load of gravel, transportation being confined to times of flood. Heavy showers and cloud-bursts sweep débris into the steep gullies, and this, carried down to the main valley, is dropped, and the channel of the stream becomes inclosed by natural dikes, so that on becoming choked at any time the torrent will take a new course and, changing from time to time, will finally have swept through an arc limited by the valley walls and varying in width from 90 to 120 degrees. It is by thus changing its channel that the stream is able to build up the conical heap at its mouth.

At Rico many of the characteristics of alluvial fans are beautifully illustrated. An inspection of the map will show the extent of the principal ones and the different relative positions of the stream channels upon the cones, and in several cases the contouring indicates the lines of former channels. The typical appearance of the alluvial fans is shown in Pl. XXI, from a photograph of the Aztec fan taken at a point upon the east side of the river near the wagon road. In this case the present channel is central. Other abandoned courses may be made out in the aspens on the north side, and another exists along the southern edge but can not be seen in the illustration. An interesting feature also shown in this photograph is the smaller fan which has been formed in front of the larger one. From the relations exhibited it appears that the great fan originally extended farther to the east than at present, but that the river in shifting its course was thrown against its base and cut away its lower portion, producing the steep bank now exhibited. During this period of cutting the channel on the fan probably had a location different from the present. Since the channel was located at the position which it now has a secondary fan has been formed by material, a portion of which seems, from the depth of the channel, to have been derived from the upper part of the main fan.

Other fans than those represented occur in Silver Creek at the mouth of Allyn Gulch and of the next gulch above upon the south side. Also a portion of the surface materials upon the hillside west of Rico may have been formed in the same manner as the fans of the lower valley, which they very closely resemble as topographic features. These have not been distinguished from the adjacent surface débris.

Calcareous spring deposits.—The Rico Mountains are well watered,

and even in the driest seasons most of the gulches contain very considerable streams which are fed by springs. The water of the springs is usually impregnated either with lime or with iron, probably of rather superficial origin, and locally these ingredients are frequently present in sufficient amounts to separate from solution and form deposits upon the surface or in the interstices of gravel or other loose surface materials. In some cases the waters, besides their mineral contents, are impregnated or accompanied by gases, such as sulphureted hydrogen and carbonic acid gas.

The generally calcareous nature of the spring water at Rico is a direct result of the richness of the prevailing sedimentary formations of the central region in carbonate of lime, but in most cases the amount of the mineral held in solution is not sufficient to give rise to important deposits of tufa. There are, however, several such deposits which are situated upon the lower slopes in localities where loose materials cover the solid rock for some distance above the springs. From this relation it seems likely that the waters travel underneath the surface of the ground from the higher elevations and, percolating through the loose surface materials, dissolve en route carbonate of lime, which they redeposit upon emerging at the surface, partly by evaporation and loss of carbonic acid and partly through the agency of the animals and plants which inhabit the boggy places about the springs. The lime is frequently deposited in such a way that ponds are formed, and in these small snails find a congenial habitat, the shells of successive generations gradually adding to the growth of the lime deposit. Moss growing in the bogs is continually saturated in the calcareous water, and becomes at first coated but finally entirely impregnated with the lime, giving rise to a spongy mass which is often found near the lime springs. Grasses, leaves, and twigs falling where the water can trickle over them are quickly entombed, and upon decaying leave their characteristic forms impressed upon the resulting rock. Leaf impressions may be found at almost any of the springs: they are especially well shown in the deposits above the wagon road south of Horse Gulch.

The principal deposits of calcareous tufa have been outlined on the map, by reference to which their extent and distribution may be seen.

At one locality the tufa has been quarried for a kiln and has found a considerable use, since it is conveniently located and produces lime of good quality.

Ferruginous deposits.—Iron-bearing springs occur at several places in the Rico Mountains, and have left local deposits of iron oxide, cementing surface debris and forming what is commonly known as "iron cap." Though occurring at other places, these ferruginous conglomerates are especially in evidence in Silver Creek above the Fort Wayne tunnel, in the upper part of the northern and western branches of Horse Gulch, and in the lower part of Horse Gulch at the base of

the northern landslide area. Their origin is probably connected with the oxidation of iron pyrites, but their occurrence can never be safely taken as a clue to the proximity of large bodies of that mineral.

Gas springs.—Emanations of carbonic acid gas and of sulphureted hydrogen accompany many springs of water in the Rico region. The former is continually escaping in large quantities in the central part of the dome, while the latter is noted in many places on the west side of the mountain group in the drainage of Stoner and Bull creeks. Both gases doubtless have their origin in chemical changes which are going on at a greater or lesser depth beneath the surface, and the waters with which they are associated may or may not be of deep-seated origin. In some places they certainly are not, for in the case of the sulphur springs the water increases and diminishes with the humidity or dryness of the season, and at certain times the flow of water ceases entirely, but the gas continues to escape. It appears that in such instances the gases have found the same channels along which the waters are circulating and that the two mix and escape together. In like manner it is notable that the carbonic acid gas, which is escaping in large quantities in various places, is far in excess of the amount which can be absorbed by the water with which it issues, and in mine workings the gas is frequently encountered where it flows up from crevices without any water at all. In one of the borings of the Atlantic Cable Company, made several years ago, a flow of gas was tapped which, being confined, is said to have had a pressure of more than 50 pounds and to have maintained it, with slight decrease, to the present time. A similar pressure is reported to have been shown by gas encountered in a bore hole in the Rico-Aspen workings.

Several tunnels in the west bank of the Dolores at Rico have struck carbonic acid gas escaping from many fissures in the highly shattered rocks in the vicinity, and a spring of water strongly charged with this gas bubbles up through the gravels of the river bed not far from the Shamrock tunnel.

Several of the carbonic springs at Rico are locally known as "soda springs," and, while no analyses have been made of their waters, there is no reason for doubting the correctness of this designation. Their waters are highly charged with gas, an excess of which escapes in the form of bubbles, and are cool and of a delicious flavor, resembling, in this respect, the waters of known soda springs at other localities in Colorado.

GLACIAL SCULPTURE OF THE BIGHORN MOUNTAINS
WYOMING

BY

FRANÇOIS E. MATTHIES

CONTENTS.

	Page.
Introduction	173
Topographic conditions	174
Climatic conditions	174
Geologic conditions	175
Postglacial conditions	175
Description of the glaciated area of the Bighorn Mountains	175
Recession of cirque walls	178
Nivation	179
Cause of glacial motion	185

ILLUSTRATIONS.

	Page
PLATE XXIII. Map of glaciated region near Cloud Peak.....	176
FIG. 1. Preglacial topography.....	174
2. Postglacial topography.....	174
3. Cross section of snowdrift site.....	181
4. Cross section of a flat valley.....	183

GLACIAL SCULPTURE OF THE BIGHORN MOUNTAINS, WYOMING.

By FRANÇOIS E. MATTHES.

INTRODUCTION.

Owing to an unusual concurrence of conditions, topographic and climatic, which governed the distribution and growth of the former glaciers of the Bighorn Mountains, this range now abounds in features of glacial sculpture showing great regularity and beauty of form. Besides being an exceptionally fruitful field for the study of cirques and their development, it offers a class of data which in many other glaciated regions are either vague or altogether absent. It is the purpose of this paper first to describe these data, and then to discuss their bearing on the cause of glacial motion.

All mountain systems which are or have been centers of local glaciation exhibit numerous examples of that type of alpine valleys which terminate at their heads in rocky amphitheatres known as "glacial cirques." These have been justly recognized as the main sources of glaciers, for the enormous quantities of snow which collect in them every winter, whether wind-blown or brought down by avalanches from the surrounding cliffs, constitute practically the only accretions to the body of the ice streams. Until lately there has been a tendency to regard a cirque basin as one which by its very form is eminently adapted to the accumulation of snow, and which from the beginning has had much the same shape. That glaciers may be able to scoop out a cirque has been suggested by Gastaldi¹ and Helland;² yet not until Mr. Willard D. Johnson propounded his views concerning the recession of amphitheatrical walls by a sapping process occurring at the bottom of "bergschrunds" have we come to look definitely upon the cirque as the peculiar and characteristic product of the action of the ice mass contained within it. Accepting Mr. Johnson's explanation of this process, as seems warrantable to me in the light of independent investigations, we must consider a cirque as a modified, preglacial, stream-worn valley, whose V-shaped cross section has been

¹Quart. Jour. Geol. Soc., Vol. XXIX.

²Ibid., Vol. XXXIII.

converted into a wider U-shaped one, and whose grade has been flattened rather than lowered. When, therefore, we study the present shape of any individual cirque the influence of the preglacial topography must be taken into account. In most glaciated regions, unfortunately, it is difficult to trace out the features of the preglacial topography. In the Swiss Alps, in Norway, and in part of the Sierra Nevada, as well as in Colorado, the cirques as a rule are only partly developed, the antecedent topography can not be restored, and no estimate can be made of the total change wrought by the ice in any particular case. In these regions it is next to impossible to find a cirque which may be set down as a complete specimen of the type. The conditions necessary for the production and preservation of such a cirque rarely occur in combination, as may be gathered from the following review. They are, first, topographic; second, climatic; third, geologic; and fourth, postglacial.

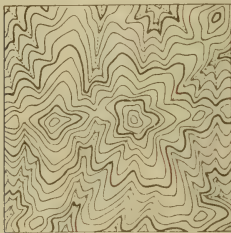


FIG. 1.—Preglacial topography.

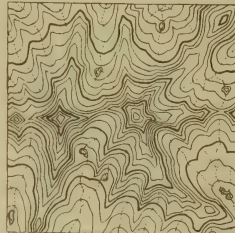


FIG. 2.—Postglacial topography.

Topographic conditions.—For typical cirque development the preglacial valleys must be situated far enough apart to admit of the necessary broadening in adjacent pairs without coalescence across interspaces.

In most high mountain ranges the preglacial valleys were close together, and as a result the spurs between the present cirques have dwindled to mere arrêtes, or have altogether vanished, while the summits and crests separating the heads of the cirques have been reduced to Matterhorn-like "aiguilles" or needles, and the lower divides to cols (see figs. 1 and 2). Since many alpine valleys fork near their upper ends, twin cirques and more complex forms often arise.

Climatic conditions.—The summits, crests, and spurs between the cirques, wherever they are wide, must remain unglaciated, otherwise the limits of the sculpturing in each cirque will be effaced.

In the majority of the mountain systems which at one time were centers of local glaciation, the precipitation was sufficient to produce continuous ice caps extending over a large part of the crests and spurs.

The line of demarcation between the work of such an ice cap and that of the cirque glaciers can not, as a rule, be definitely established. Moreover, in such regions as Switzerland and the Scandinavian peninsula the effect of an ice sheet of continental proportions adds to the confusion and renders the study of cirque sculpturing still more unsatisfactory. In general, whenever in any region glaciation has ceased to be local the pristine outlines of the cirques, as well as those of lesser features illustrative of the incipient stages of glacial sculpturing, will be lost to the student.

Geologic conditions.—In order that regular, simple forms may be produced, the rock in which the cirques are sculptured must be both fairly homogeneous in texture and uniform in hardness.

The obscuring effects of concentric shelling and of pronounced cleavage and jointing planes, as well as the alternation of hard and soft sedimentary strata, are well illustrated in the Sierra Nevada and the Alps.

Postglacial conditions.—It is necessary that the characteristic forms left by the ice shall not be marred by postglacial remodeling.

On account of the rapid weathering of the exposed rock of the amphitheatrical walls and the consequent accumulation of talus at their bases, many of the finest cirques in the Alps and in Colorado are being rapidly converted into vast semicircular hoppers, while the glaciated surfaces lower down in the canyons are becoming effectually concealed by encroaching vegetation. Postglacial stream erosion is equally detrimental, and it has done much in regions like the Alps to destroy evidences of great value.

When we remember that most of our knowledge of glacial cirques has been gathered in the Swiss Alps, in Norway, and in the Sierra Nevada, regions where the above-stated conditions have seldom operated in unison, we shall better appreciate the difficulties under which glacialists have labored, and shall realize what an unsatisfactory field for the study of cirques has so far been available. To all these regions the Bighorn Mountains stand in favorable contrast; indeed, they scarcely have a rival.

DESCRIPTION OF THE GLACIATED AREA OF THE BIGHORN MOUNTAINS.

The Bighorn Mountains form a single, broad range extending in a northwesterly direction from the center of Wyoming into the southern part of Montana. They consist essentially of one large anticline, the granitic core of which has been exposed by denudation for a distance of about 70 miles along the highest part of the crest line. The eastern flank rises abruptly from the plains of Wyoming, which extend eastward for hundreds of miles, while the western flank declines much

more gently to the broad basin of the Bighorn River. These plains, neither of which has ever been covered by the continental ice sheet, have a mean altitude of about 4,000 feet. The crest of the range varies between 8,000 and 13,000 feet in elevation. Its highest point, known as Cloud Peak, 13,165 feet high, is the remnant of a massive dome. The width of the range in this neighborhood is close to 40 miles.

The area in which glaciation has taken place extends for over 30 miles along the crest. The accompanying map (Pl. XXIII), prepared during the summers of 1897, 1898, and 1899, shows the greater part of it.

None of the trunk glaciers which flowed from this region ever reached the plains; the longest one, that in the valley of West Tensleep Creek, had a length of 18 miles, its farthest terminal moraines being at an altitude of 6,900 feet, or nearly 5,000 feet below the floors of the highest cirques at its head (see 13 and 18, Pl. XXIII).¹

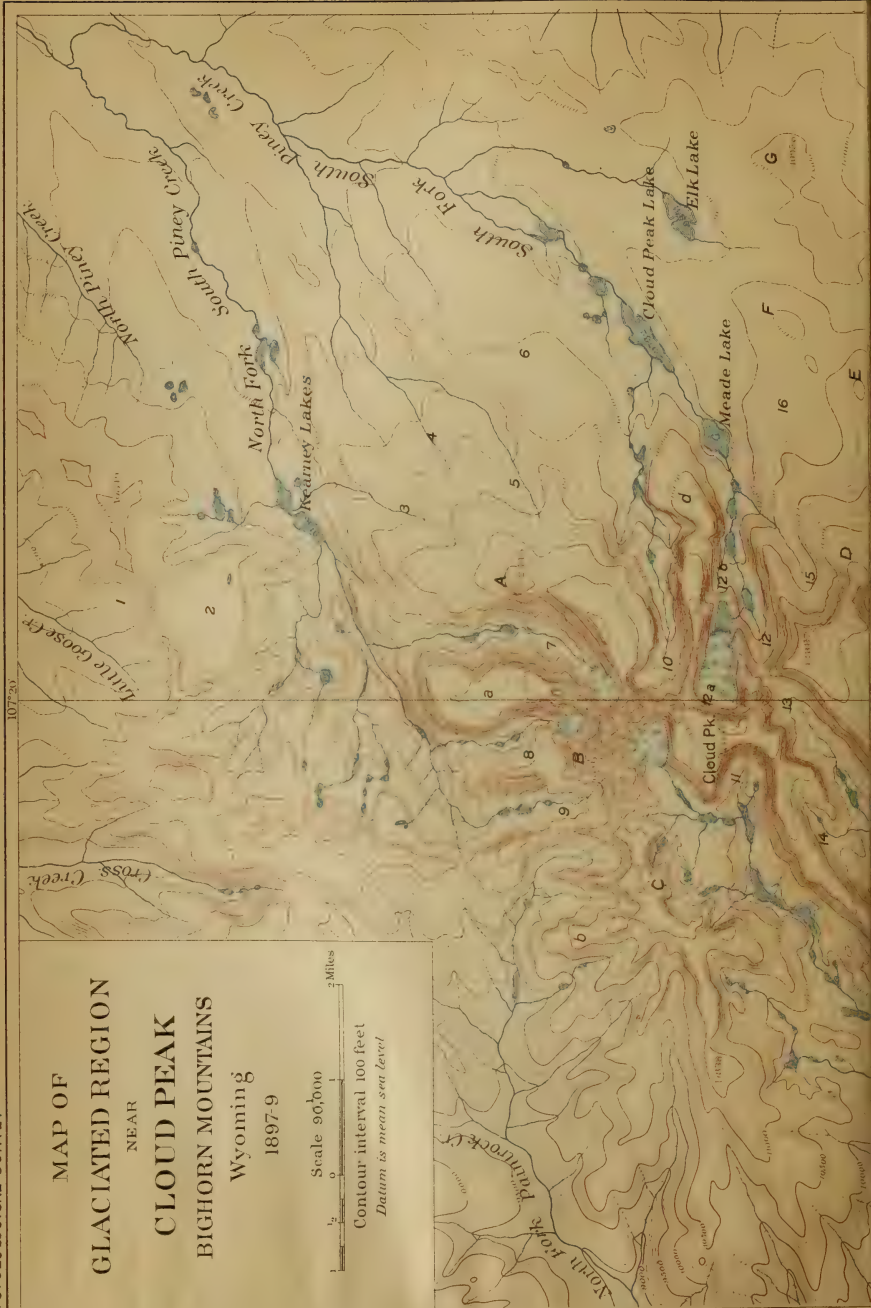
By far the most conspicuous features of the area mapped are the deep glacial canyons, with their precipitous amphitheatres, contrasting strongly with the smooth outlines of the summits between them. Those which appeal to the tourist most and offer the finest scenic effect are situated north of peaks A, B, and C. The magnificent canyon 7, cutting through no less than three peaks; the almost isolated table a; the fantastic comb ridges or *arrêtes*, and the pinnacles of the main range form a group of topographic features worthy of a pilgrimage. The most fruitful field for study, however, lies among the rounded summits, crests, and spurs of that part of the range between the headwaters of Tensleep and Clear creeks. For, while the cirques north of B and C have developed in parallel valleys situated side by side, and have consequently interfered with one another in their broadening, those numbered 23, 24, 25, 33, 34, 35, 39, etc., remain separated by broad, massive spurs, and have developed unhindered to their full extent. Some, it is true, such as 22, 23, 35, are complex forms, owing to the forking of the preglacial valleys, but the others are of simple, often straight form; they may be termed *orthotypical* (see 25, 39). Besides, a close inspection has shown that the summits, crests, and spurs between them have never suffered glacial erosion; that is to say, there has never been a continuous ice cap on this range. Consequently the outlines of these cirques and canyons are strictly the products of the sculpturing done by the ice in each of them, and the intermediate surfaces are virtually representative of the preglacial topography. Here, then, the topographic and climatic conditions have combined in a manner most favorable for study.

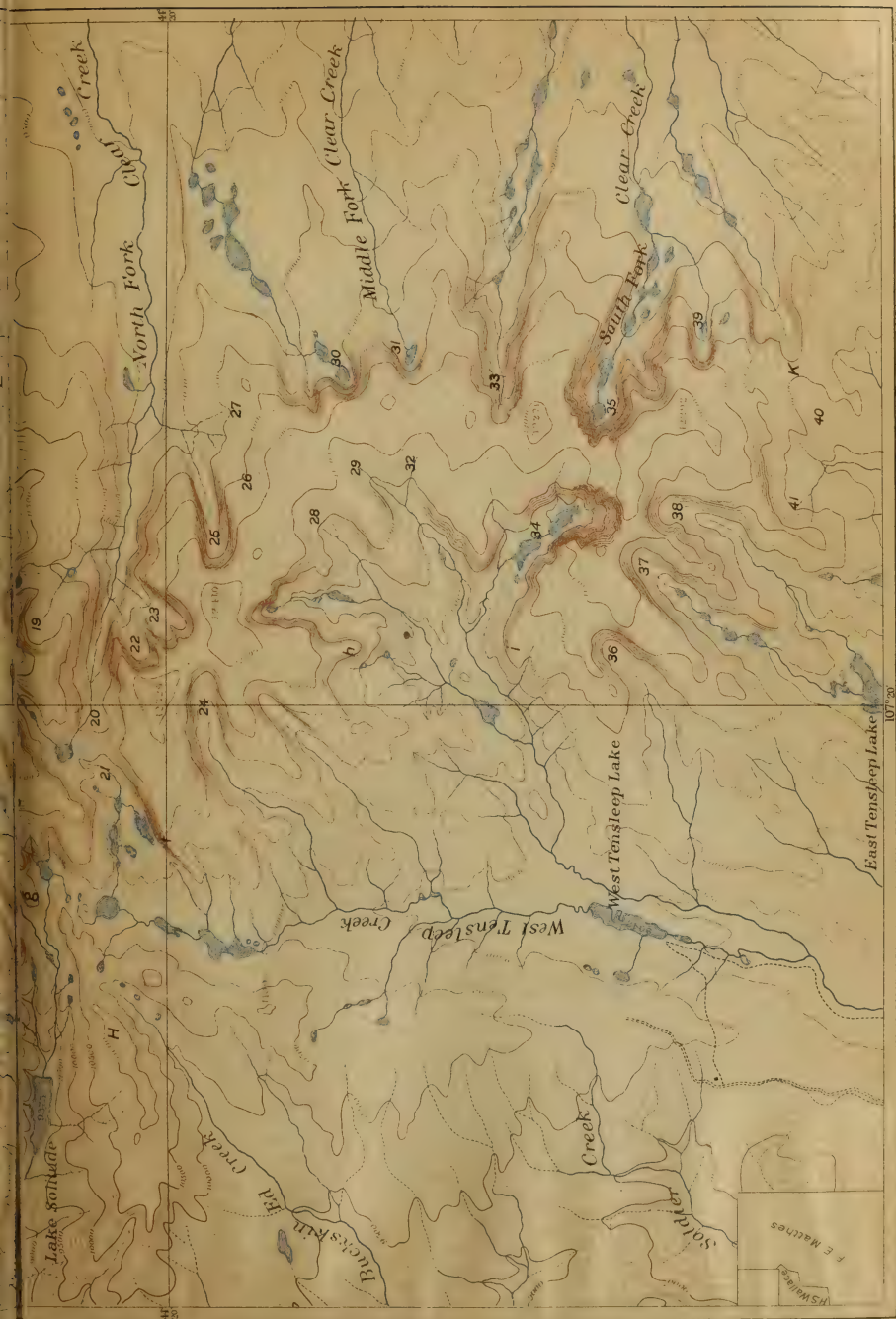
While humps and irregularities of minor importance abound in the larger canyons, those numbered 22, 23, 25, 39, are singularly free from them. The granite in which 25 and 39 were hewn out is fairly homogeneous; its joints run in various directions and do not affect the

¹ The peaks and spurs referred to are lettered on the map in alphabetical order from north to south, while the cirques and other valleys are numbered in a similar manner.

MAP OF
GLACIATED REGION
NEAR
CLOUD PEAK
BIGHORN MOUNTAINS
Wyoming
1897-9

Scale 90,000
0 1 2 Miles
Contour interval 100 feet
Datum is mean sea level





shapes of the cirques. In 17, 19, 41, the inclination of the joint planes has resulted in the production of a steeper grade than usual, while in the case of the cirques on the east and west faces of Cloud Peak the steep dip of the joint planes has caused the cliffs to be more nearly vertical than elsewhere. Yet in general form and outline none of the cirques can be said to greatly differ. On the whole, then, the geologic conditions also are favorable.

Nearly all of the cirques shown on the map are in a good state of preservation. The crumbling of the walls by postglacial weathering has not been extensive enough to materially change their aspect, and the accumulation of talus is correspondingly moderate. The canyon 33 has, perhaps, suffered most in this respect; its upper end is now once more V-shaped on account of the talus slopes. In 20 these have just begun to meet. Not ten years ago a well-worn pack trail extended up this valley and passed over the divide into the Tensleep Creek drainage. This trail has now been abandoned as impracticable. On the other hand there are many localities where the talus is insignificant, as, for instance, at f, and in canyons 10, 12, 21, 22, 23, 25, 39, and others.

Postglacial stream erosion has been very slight. It has effected no appreciable changes in the granite floors of the cirques and canyons, and its most important results are found in the silting up of small morainal ponds. While the valleys formerly occupied by the trunk glaciers, since they are floored with morainal material, are now covered by dense pine forests, the cirques and canyons, as well as the spurs between them, are all situated well above the timber line, which closely follows the 10,000-foot contour. For reasons which will appear later, occasional patches of alpine scrub fir and dwarf willows, as well as grass, flowering plants, and moss, find nourishment on the high, unglaciated surfaces; but the floors of the glaciated cirques and canyons are virtually devoid of all vegetation or humus. Their features are, therefore, left wholly unmasked by the products of organic agencies.

From the foregoing brief description it is apparent that the four conditions essential to the production and preservation of complete cirques—that is, of features of glacial sculpture generally, did in a large measure obtain in the Bighorn Mountains. The original valleys were, in places, far apart, and the cirques which have since formed in them have developed undisturbed; the structure of the rock has been favorable to the evolution of simple forms, and, on account of the absence of an ice cap, the present extent of each cirque is truly indicative of the sculpturing done within it.

The changes wrought by the postglacial agencies—weathering, erosion, and vegetation, which have been so active in obliterating the glacial features of the Alps—are here as a rule too insignificant to complicate the investigation.

RECESSION OF CIRQUE WALLS.

At the annual meeting of the Geological Society of America, held December 28, 1898,¹ Mr. Willard D. Johnson presented a theory in explanation of the recession of the amphitheatral walls of cirques, ascribing it to "sharply localized and abnormally vigorous weathering," by rapid alternation of freezing and thawing at the exposed bottoms of "bergschrunds." According to him, the effect is essentially that of sapping the walls at their base, thus causing them to recede. Similar action at the bottoms of those transverse crevasses which occur where the glacier loses its continuity over the edges of cross benches produces the recession and accentuation of these benches. Since the effect of a continuous ice mass of great thickness is to protect its bed against oscillations of temperature, maintaining it at 32° F., this explanation seems a rational one; for, while on the one hand the recession of the cirque walls can not be due to scour, and is essentially the result of a quarrying process, on the other hand the "bergschrunds" proper as well as the lower transverse crevasses are the only channels through which the air, with its fluctuating temperature, is admitted to the bed of the glacier. While we have no experimental data upon this point, yet it is reasonable to assume that, on account of the water running in subglacial channels, a downward draft is produced in the "bergschrunds" and the other crevasses in much the same manner as in the manholes of a sewer.

Close investigation of the floors and terminating walls of the glacial cirques in the Bighorn Mountains fully bears out Mr. Johnson's views. Step-like transverse benches occur in many of the canyons shown on the map, notably in those marked 8, 9, 10, 12, 17, 18, 19, and 34. The cirque walls appear plainly to have receded on account of a quarrying process, while on the other hand the lower parts of the canyons appear merely to have been scoured out by the passing ice. In some cases the recession of opposing cirque walls has reduced the divide between them to a thin arrête (see 7 and 8 and 7 and 10); in other cases these arrêtes have been leveled down to cols, as between 8 and 9, 12 and 13, and 20 and 21. In the latter instance this has resulted in the capture of the drainage of 18 by 20.

Recession there has been, beyond a doubt. The question is, how great a distance has been covered by cliff recession in any particular case; in other words, what was the original point in any valley at which a cirque first began to develop? Must we suppose, in the case of canyon 7, for example, that the cirque wall has receded from the canyon mouth clear back to its present site, a distance of over 2 miles? Or must we assume that the cirque formed at the head of the preglacial valley,

¹ For abstract see *Science*, new series, Vol. IX, 1899, pp. 106 and 112-113.

carrying it back toward the divide, and that the greater part of the canyon is the product of glacial scouring? A comparison of the cirques on the map reveals that, while the cirque walls of 7, 8, 9, 10, 11, 12, 13, 15, etc., have receded beyond the heads of their respective valleys, those of 14, 18, 28, 29, and 31 have not done so, for the upper ends of the preglacial valleys still remain unglaciated above the present sites of the amphitheaters. (The cirque walls in 28 and 29 are not high enough to appear distinctly on the map, owing to the large contour interval.) It is evident, then, that a cirque does not necessarily form at the head of a preglacial valley, but originates at the highest point in it which satisfies the conditions indispensable to its development. These conditions, whatever they be, did not obtain in the upper parts of 14, 18, 28, and 29, otherwise they also would have been glaciated. If parts of valleys can remain unglaciated, should we not expect to find entire valleys similarly exempt? Such unglaciated valleys do indeed occur in these mountains, and they are the more striking where they are situated amidst the deepest and most heavily glaciated canyons (see 3, 4, 26, and 27). They were undoubtedly subject to the same climatic conditions as the neighboring canyons; 26 and 27 must have shared the same mean annual temperature and the same snowfall with the preglacial valley 25. There must then have been other circumstances which determined what valleys should become glaciated; that is to say, whether cirques should develop in them; and if so, at what particular places.

Before pursuing this inquiry further, it will be helpful to first study in detail the character of these unglaciated surfaces.

NIVATION.

We have thus far described the rounded summits, crests, and spurs, also the valleys just mentioned, as "unglaciated." They do not, in fact, offer the slightest evidence of glacial scour, and are, as a rule, densely littered with rock disintegrating in situ.

It would nevertheless be absurd to suppose that these large areas remained bare throughout the period of glaciation. Even now, when the large glaciers which once filled the canyons have almost vanished, large snowdrifts accumulate every winter on the unglaciated slopes. A single severe winter is capable of producing snow banks which all the heat of the ensuing summer can not remove. According to my own observations the snowdrifts of the exceptionally severe winter of 1898-99 were still from 25 to 50 feet deep and often 1,000 feet long at the close of the following summer in places where I had found no trace of snow the preceding year. A number of these drifts were on slopes having a southern exposure. Most probably, therefore, in glacial times a layer of *névé* covered the greater part of this unglaciated

ciated area, more especially its depressions, and since there is no evidence of scour or of transportation of loose-rock *débris* it is to be inferred that this *névé* mass remained quiescent. That this inference is borne out by another class of evidence I shall now endeavor to show.

While I was traveling over the smooth, grassy slopes of that part of the Bighorn Range locally known as the Bald Mountain district, which lies outside of the glaciated area and is peculiar on account of its large and smoothly rounded features, my attention was repeatedly attracted by certain bare and desolate-looking areas, the exposed soil of which contrasted strikingly with the green of the surrounding sod. They were each invariably associated with some more or less marked accident in the slope of the mountain side, and they were generally situated on slopes having a northeasterly exposure. A clew as to the reason of their occurrence soon presented itself. A number were found partly covered with the remnants of snowdrifts, fast disappearing under the July sun. These drifts had no doubt accumulated in the lee of the escarpments and swells against which they were invariably situated. The prevailing winds being southwesterly in this region the northeasterly slopes naturally offer the most favorable conditions for the formation of such drifts. These, therefore, recur upon the same sites periodically and modify the surface configuration sufficiently to render them conspicuous.

Observations on a number of drift sites, as well as on drifts of all sizes and in all stages of ablation, disclose the following facts:

1. The soil exposed by the retreating edges of the drift appears loosened up, porous, and crumbling.
2. A layer of exceedingly fine mud is deposited on the lower portion of the site, especially at the toe of the drift.
3. The site is devoid of drainage lines; that is, it shows no effects of concentrated erosion in well-defined channels.
4. The site is more or less sunk into the face of the slope—the steeper the slope the more pronounced the depression.
5. The slope of the site tends to become concave in profile as well as in horizontal contour.
6. There is no indication of scour or of transportation of material as if by movement of the snow mass.

The looseness of the soil around the drift must be attributed to frequently recurrent frost action. The drift acts as a blanket in protecting its bed from oscillations of temperature, but the water derived from melting at its edges on summer days naturally permeates the soil in the immediate vicinity. This zone of water-soaked soil is exposed to those sharp frosts which at such altitudes occur regularly each night, except during a few weeks in August; and as the edges of the shrinking snow mass retreat new portions of its site are thereby

exposed. Owing to the oft-repeated distending action of freezing water in the capillaries of the soil, the latter loses its cohesion and becomes finely divided. Upon thawing, the soil water carries with it a portion of the fine material thus loosened for such distance as it may have transporting power. Since there are no well-worn channels on any of the sites inspected, it may be inferred that the water from the upper edges of the drift percolates slowly under the mass in sheets without exerting appreciable erosive power. This fact was particularly well demonstrated on some sites visited by me, from which the snow had almost disappeared, and on which the water-soaked and porous soil could still be seen undisturbed, presenting a somewhat honeycombed appearance, devoid of eroded channels. It was barely passable on foot.

The steeper portions of a snowdrift site, whenever exposed to frost action as described, have a tendency to become accentuated as the loose material is carried down by water, or to crumble. A drift lying against

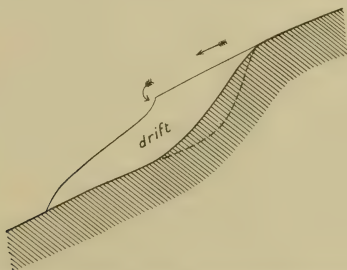


FIG. 3.—Cross section of a snowdrift site. Dotted line shows position of escarpment due to recession.

a deep escarpment will, therefore, in time accentuate the slope thereof, and if the drift occupies but a small portion of a slope its site will tend to become depressed (see fig. 3). This would naturally be less pronounced in the case of flat or gently sloping sites. Owing to the frequent oscillations of the edge and the successive exposure of different parts of the site to frost action, the area thus affected will have no well-defined boundaries. The more accentuated slopes will pass insensibly into the flatter ones, and the general tendency will be to give the drift site a cross section of smoothly curved outline, and ordinarily concave. Furthermore, the retreating edge of a snowdrift of any thickness tends to assume a rounded outline, ablation being unfavorable to the production of sharp corners or of angularity of any kind. The outlines of drift sites will therefore tend to have a similar form, and, since an ordinary drift site is hollow to begin with, the result is in general that its slopes are concave in profile as well as in horizontal contour.

That snowdrifts have no sliding motion appears certain in view of the fact that no signs characteristic of such motion are to be found on any site, and that even the finest soil under them remains in place.

From this rather brief study of snowdrifts and their sites we infer:

1. That snowdrifts do not form except in the presence of favorable topographic features.
2. That the effect of their presence is to accentuate these features by frost action at their peripheries.
3. That they tend to protect their sites against aqueous erosion.
4. That they favor the formation of deposits of fine mud.
5. That they have no sliding motion.

To return to the unglaciated slopes and valleys, which, as we have reasons to believe, were largely covered with quiescent snow or *névé*, let us now see whether they show any effects similar to those produced by snowdrifts.

All the high peaks and slopes, which on the map appear so strangely smooth of outline, possess an extremely rough surface in detail, toilsome to climb. Rapid weathering at the joint cracks has loosened vast numbers of angular blocks of granite of all sizes. Wherever the slope is at all steep fine material is not retained, and as the climber lifts himself from one block to another the sound of trickling water reaches him from the depth of the gaping holes under his feet. Wherever the slope is comparatively flat, the blocks are embedded in a thick layer of soil and small angular fragments, covered with moss, or, on the lower reaches, with grass and patches of alpine scrub fir. The flanks of peaks, such as A, D, E, F, G, and the summits of the main range farther south are essentially made up of steep, rocky slopes and irregular benches of fine material, alternating with each other, but of so little prominence as not to influence the shapes of the masses. That these benches are favorable to the formation of snowdrifts is demonstrated by the fact that even now many drifts collect on them every winter. I had several opportunities during the falls of 1898 and 1899 to watch the effect of snowstorms on these peaks. Their appearance at the end of each storm was a mottled one, the benches presenting a brilliant white, while the rocks on the steeper slopes between remained mostly bare. Long after the snow had disappeared from the latter the drifts on the benches were still present.

The *névé* which once lay on these peaks must be considered as having been made up of a large number of drifts, each occupying a bench and producing thereon the present layer of fine material, partly by preventing that already there from being carried away by water, and partly by arresting the mud brought from under the blocks on the steeper slope above it.

Even the most casual observation suffices to impress one with the smoothness and the delicate green color of the surface of such valleys

as 3, 4, 5, 16, 26, and 27, in contrast with the rough and brown spurs between them. They afford the best traveling to the mountaineer, the rocks being embedded in a compacted mass of small, angular *débris* and mud, a natural macadam, as it were, such as may be found on the benches on the peaks. Their cross section is generally of a shallow cup shape, and numerous rills take the place of a central channel, which begins to appear only in the lower portion. Wherever the *débris* is loose the courses of these rills are marked merely by narrow strips devoid of soil and vegetation, the water trickling under and between the fragments. In other places, where the *débris* is more compact, the water remains at the surface and its channels are choked with moss. I encountered many large drifts in valleys of this description, and there can be no doubt that their characteristics are largely due to the presence of quiescent *névé* at the time when the neighboring cirques were filled with large glaciers.

If we consider their original cross section as flat V-shaped (fig. 4), disintegrated rock on those parts of the two slopes, which, owing to the frequent oscillations of the edges of the *névé* mass, were exposed to

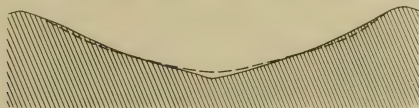


FIG. 4.—Cross section of a flat valley. Dotted line shows new surface produced by nivation.

frost action, would be loosened and carried down under the drift, to be deposited at the bottom of the cross section. From our observations on existing drifts we know that stream erosion is arrested under the *névé*; the central channel would therefore gradually fill up with the material brought down from either side and tend to become obliterated.

The effects of the occupation by quiescent *névé* are thus to convert shallow V-shaped valleys into flat U-shaped ones and to efface their drainage lines without material change of grade. These *névé* effects, which are wholly different from those produced by glaciation, I shall, for the sake of brevity, speak of as effects of *nivation*, the valleys exhibiting them having been *nivated*.

Examples are numerous. The finest may be found on the east side of the peak A, on the flanks of G, and above the amphitheatres of 14, 18, 28, 29, and 31. Of particular interest are the wide and smooth depressions northwest and southeast of E and F, in which the original drainage lines have completely disappeared, and have been replaced by shallow rills choked with grass and alpine dwarf willows. The wide flat 6 is of less value in this connection, its surface being too irregular and broken. Its lower portion is covered with lateral moraines supporting a dense forest, and has thereby been converted into a veritable

wilderness. By far the most remarkable example of nivation exists at 2, a large expanse of grass and willows, swampy and treacherous, sloping up in gentle, sweeping curves to the encircling sharp crests and pinnacles. The glacier which once flowed past this bench barely reached to its lower edge, and did not deposit any moraines upon it. The tops of the highest spruce trees along the timber line, which coincides very nearly with the lateral moraines, are just visible above the edge of the flat.

A glance at the nivated areas just described impresses one strongly with their general smoothness and the wavy outlines of their features, which stand in marked contrast with the broken surface and angularity of the glaciated canyons and cirques.

Intermediate between these two types of topography is a third, more variable perhaps, and less easily described, which, to some extent, partakes of the nature of both. It is best typified in the region near the headwaters of Little Goose and North Piney creeks. Along the crest of the range between these two creeks are many cirque-like valleys separated by narrow, angular spurs. They are deeper than those which we have just considered, and at the same time they can scarcely be classed with such pronounced canyons as 7 and 25. In them we find the evidences of nivation alongside of those of true glaciation, the latter usually on a small scale. At the very head of Little Goose Creek are two cirque-like valleys which may be regarded as typical of this class. The amphitheater walls are not pronounced, nor could I find any signs of glacial motion, such as striation. There is, however, a small amount of morainal material, not in distinct heaps but rather spread out, lower down in the valley. On the other hand the bottoms of the cirques are not clean swept, but are heavily cumbered with fine material. Postglacial talus was present in such small quantities, especially in No. 1, and looked so fresh, that it was easily distinguishable. We must infer from this that true glacial motion existed only during a short time in the *névé* occupying these valleys, and that most of the time it remained quiescent and acted like a large snowdrift. It may be considered as a case of incipient glaciation. Similar conditions, though less distinct, exist in some of the smaller valleys to the north-east, until finally we find some in which no signs of glaciation can be traced at all, only "nivation" being in evidence. In this manner glaciated forms are seen to shade out into nivated forms; and it is possible to establish a complete series of gradations from the deepest glaciated cirque to the most featureless nivated flat.

However interesting these cases may be, they are not so instructive as another category of valleys, much more numerous in these mountains than any of those yet described. Those marked 28, 29, and 40 are typical examples. Their upper ends are solely nivated, while their lower ends are undoubtedly glaciated and well scoured out.

In some (as in 29) the line of demarkation between the two processes is easily found, there being a small cliff resembling more or less an amphitheater wall. In others, however, especially those whose increase in depth is very gradual, there is no sharply defined boundary to be found; there is apparently a short stretch over which the *névé* sometimes slid and sometimes remained stationary. In general, the more rapid the increase of the depth of the valley, the more distinct is the boundary line between the nivated and the glaciated areas.

CAUSE OF GLACIAL MOTION.

A cirque is essentially the product of a "bergschrund." Were it not for the opportunity this great crevasse offers to the outside air to reach the foot of the cirque wall, the latter would have no tendency to recede; indeed, no cirque would form at all. Every amphitheater shown on the map must therefore be regarded as an indication of the former existence of a "bergschrund," paralleling the curve of its head wall and opening to its foot.

The "bergschrund" itself is merely a crevasse, or a line of crevasses, which extends along the cirque wall and opens every spring by the motion of the *névé* on its downstream side. Sometimes, it is true, there are two or more parallel lines of crevasses, produced by transverse benches near the head of the cirque; but in the most nearly perfect cirques the "bergschrund" is one single rent. A beautiful example exists at the head of the small glacier on the east side of Cloud Peak.

We have seen that in valleys like 14, 18, 28, 29, and 32 the evidences of glacial motion, such as scouring and polishing of the bed, extended as far up as the cirque wall; above it there are only signs of nivation. The "bergschrund" constitutes, then, the dividing line between the moving *névé* and the quiescent *névé*; it is the upper limit of glacial motion—that is, it indicates that place in any valley above which the conditions essential to the production of glacial motion cease to exist. The law governing the location of the "bergschrund" is, therefore, intimately connected with the cause of glacial motion.

It has been suggested by Rev. Coult's Trotter¹ that the lower layers of a *névé* mass must be raised to the melting point in order that they may slide over the bed. The "bergschrund" would, then, mark that line above which the necessary temperature conditions do not exist, the *névé* remaining stationary and perpetually frozen to the ground. According to Mr. Trotter, the "bergschrund" would coincide with an isothermal surface, that of the mean annual temperature of 32° F., and one might be led to conclude that the upper limit of glacial motion is, at any point, determined by the elevation of the spheroid of 32° F.

¹ Proc. Roy. Soc., 1885, Vol. XXXVIII, pp. 92-108.

This, however, seems wholly unwarranted. The fact that the mean annual temperature at any place is 32° F. does not preclude the occurrence of periodical thaw; indeed, it rather implies it. The stationary névé described by Mr. Trotter as having little depth does not necessarily remain below the freezing point throughout its mass summer and winter; it does melt away on the lower peaks and arrêtes, as may be seen on the Swiss Alps. Yet it does not slide, glacier fashion, even then; it remains quiescent, frozen or not frozen. Whether the quiescent névé in the Bighorn Mountains was at one time permanently frozen to the ground it is difficult to determine. The effects of nivation, which imply recurrent thaw, may have been produced only at the beginning of the period of glaciation, and again toward its end. Certain it is, however, that no motion occurred in these névé masses at any time, even when considerable melting took place and nivation was proceeding most actively. The map shows us that quiescent névé did not occur above the "bergschrand" alone. The effects of glaciation and nivation are found side by side at all elevations from 10,000 feet up, with both northerly and southerly exposures. There is even a case where quiescent névé occurred below the terminus of a short glacier, namely, at 31, where the lowest terminal moraines are situated near the 10,400-foot contour, while the effects of nivation continue for more than half a mile farther down the valley. If the temperature conditions at this altitude were sufficient to check the advance of the glacier by ablation, the quiescent névé in that neighborhood certainly can not have been frozen to the ground, but most likely disappeared entirely every summer.

If the "bergschrand" coincides with some fixed isothermal surface, such as the spheroid of 32° F. or that of perpetual frost, how are we, for example, to account for the occurrence of two "bergschrand," one some 800 feet above the other (see 12a and 12b), or for the fact that the upper cirque still contains an ice mass possessing all the properties of a glacier, while the névé in the lower one has entirely disappeared? And why has there never been any "bergschrand" at all in valleys like 26 and 27, alongside of such a prominent instance of glacial sculpture as 25? If the quiescent névé was ever permanently frozen in the nivated areas, many of the "bergschrand" must have been situated well above the spheroid of perpetual frost. Yet there is no difference between cirques formed at an elevation of 12,000 and those at 10,000 feet; there is no evidence that the quarrying process in the highest cirques has been less vigorous than in the lowest ones. They may all have been situated in the region of perpetual frost, like those of the Mount St. Elias region, which occur at elevations of 13,000 feet and over. The sculpturing effect is not different from that which can be observed in the lowest cirques of the Alps, from which glaciers still emanate. In short, it matters not what the mean

annual temperature of the air is at the "bergschrund," the temperature at the bottom of the glacier is constant, and whatever frost action takes place at the foot of the "bergschrund" is due to the periodical fluctuations of temperature of the outside air.

We may conclude, then, that the location of the "bergschrund" is determined irrespective of any isothermal surface and that atmospheric temperature does not operate as a factor in the production of glacial motion.

The snow line on any mountain range is that line at which ablation equals precipitation. The influence of terrestrial heat, of warm air currents, and evaporation at great altitudes being so slight as to be negligible, the sun is there virtually the only source of heat operative in the removal of snow. At the elevation of the snow line, then, the total amount of solar heat received during the year is just sufficient to melt the entire annual snowfall; and since the latter varies with the humidity of the climate, the snow line will, other things being equal, be higher in a dry region than in a moist one. For regions having the same annual snowfall it is a line of equal caloric conditions; but it is not necessarily coincident with any particular isotherm, for the mean annual temperature at any place is no function of the amount of solar heat received by it during the year. It follows, then, that there is no fixed relation between the lower limit of perennial snow and any isothermal spheroid, and the conditions obtaining at the snow line on any mountain range must be considered as peculiar to the locality.

In the region of perpetual snow, part of the snowfall of one winter is still on the ground at the beginning of the next one. As the accumulation of snow proceeds, the entire area above the snow line must in the course of time be converted into a vast *névé* field, and more or less extensive glaciation takes place. Complete glaciation—that is, occupation by a continuous ice sheet produced by the confluence of many minor glacial streams—is not, however, the invariable result. While examples of it may be seen in Greenland and the arctic lands to the west of it, and others are known to have existed both in Europe and on this continent, it is manifestly not a universal occurrence. In many mountain regions a local ice cap of small extent has existed within the limits of the area of perennial snow; in some cases such an ice cap has been totally absent. The actually glaciated part of such a region is but a very small fraction of the entire area situated above the snow line. In the Bighorn Mountains glaciation has remained confined to certain valleys only; and, as we have seen, such a thing as a continuous ice cap has never covered their crest. Undoubtedly all the nivated areas were situated above the snow line; they were once buried under a thick layer of *névé*; yet no glaciers ever flowed from them, and no cirques were ever sculptured there. What, then, caused

the *névé* in these areas to remain quiescent while glaciers from 10 to 18 miles in length flowed in the neighboring canyons? The nivated and glaciated areas shared the same snowfall and the same climatic conditions, and if these were favorable to the production of glaciers in the one case, they must have been equally favorable in the other. Moreover, we have satisfied ourselves that the location of the amphitheaters—that is, of the “*bergschrunds*”—is not dependent upon or in any way connected with temperature conditions. That being the case, the only other explanation that suggests itself is that the distribution of the glaciers was wholly governed by conditions of a topographic nature.

Drifting snow collects wherever a topographic feature produces eddying of the wind; and the tendency of a drift is, in general, to completely fill the space in which eddies occur (for winds of one direction) until its surface is such as to be continuously wind swept throughout. This surface may subsequently be changed by winds from other directions, especially if the snow remains dry and light; and readjustments will continually occur as long as it remains in that condition and whenever it receives additions to its mass. If deposition continues in excess of ablation there must come a time when the snow completely buries the features of the topography, and their influence upon the distribution of the snow will no longer be felt. There is then for any type of country a minimum snowfall necessary to neutralize the distributing power of its topographic features. Whenever the annual snowfall is greater than this minimum, it will produce in the course of time a continuous *névé* or ice cap, which may have glacial motion in any or all of its parts. As long as the annual precipitation falls short of this amount, drifts of limited extent and depth will result—that is to say, their location and horizontal dimensions will be conformable to the contours of the ground and their vertical dimensions to its profile. Especially will this be the case on the elevated slopes of a high mountain range, where the snow remains dry and powdery for some time and where high winds are prevalent from one direction.

From our studies of the effects of nivation we know that the nivated valleys have undergone but little change. We may safely consider them in this discussion as identical with the preglacial forms. As the contour map shows, they are without exception shallow. Their cross sections are usually less than 100 feet in depth; and whenever they exceed that amount their width is so great in comparison that they can scarcely be termed deep. The nivated areas in general present fairly smooth, rounded features, devoid of any abrupt accident; their configuration throughout is such as to offer no opportunity for the accumulation of snowdrifts of great thickness. In areas of this type it seems to me beyond doubt that the depth of the *névé* nowhere exceeded that of the valleys. The climate of central Wyoming is a

ERRATUM.

[Twenty-first Annual Report United States Geological Survey, Part II.]

On page 189, second paragraph, eleventh line, for "east spur of h"
read: east spur of H.

semiarid one, and while the snowfall in the Bighorn Mountains is much greater than on the adjacent plains, yet it is small in comparison with that occurring in the mountains of Washington, Oregon, and California. Even at the time of maximum glaciation it must have been rather limited. At all events it was not sufficient to counterbalance the distributing power of the topographic features; and, that being the case, the depth of the *névé* must have been limited by the depth of the valleys. Besides, it is quite probable that vigorous ablation took place in summer during the greater part of the period of glaciation, if not at all times. The nivated benches on the flanks of the peaks indicate frequently recurrent frost action due to oscillations of the *névé* edge; they must have been periodically bared by ablation. It seems likely, then, that ablation was a powerful agent in reducing the *névé* masses, and that it combined with the peculiar topography, the prevailing winds, and the moderate snowfall in preventing the *névé* from acquiring any considerable depth in the nivated areas and from forming a continuous ice cap on any part of the range.

Turning now to the glaciated canyons, we find great depth a conspicuous and ever-present feature. The majority are over 1,000 feet deep, and even those like 28, 29, and 40, in which the effects of glaciation are least pronounced, have cross sections several hundred feet in depth. The thickness of the ice masses which they once contained is easily gauged from the abrasion shown at such corners as *h* and *i*, and along the edges of the table *a*. The glaciers in the adjacent canyons must have been from 1,000 to 1,500 feet thick. Those issuing from canyons 13 and 14 were high enough to overrun the spur *g* as high as *e*. Their combined stream must have been enormous, for on reaching the east spur of *h* it split into three bodies, one flowing toward Lake Solitude, abrading the north side of *H* as high as the 10,800-foot contour, another overflowing into the valley of Buckskin Ed Creek for a distance of 4 miles, and the remainder turning south down the valley of West Tensleep Creek, forming, with other tributaries, a trunk glacier 18 miles long.

The difference in depth between the glaciated canyons and the nivated valleys is obvious from the map alone; but while the latter are fairly representative of the preglacial valleys the former have been so extensively altered by glaciation that it is difficult in most instances to form a conception of their preglacial aspect. The recession of the cirque walls and the flattening of the grades have deepened these canyons considerably, especially toward their heads, and it would therefore be unwarrantable to fix the depth of the preglacial valleys by any measurements now obtainable. Nevertheless it seems certain that they were very much deeper than any of the nivated valleys and offered opportunity for the accumulation of great depths of *névé*; and we infer that, in general, the depth of a valley, or, more strictly,

the depth of the *névé* in it, had much to do with its glaciation, and consequently with the location of the "bergschrund." In cases like 14 and 18 there is little doubt that the upper portions remained nivated solely on account of their shallowness, and that the cirques began to form at the highest place in each valley at which the *névé* attained the minimum thickness necessary for the opening of a "bergschrund"—that is to say, for the production of glacial motion. While in these particular valleys the depth of the cirques is not representative of that minimum depth, on account of the recession of their walls, there are a few valleys, such as 28, 29, 40, etc., in which a fair estimate can be obtained. In them there are no marked cirque walls, and the "bergschruns" seem to have oscillated over a short stretch. As a result there has been little excavation and the present grade of the valley is nearly what it was in preglacial times. The depth of these valleys increases from nothing at the head downward. The thickness of the *névé* most probably increased similarly, and at the site of the "bergschrund" must have occurred the greatest thickness at which *névé* can remain quiescent—that is, the minimum thickness required for the production of glacial motion on that grade. It will be safe to assume that thickness as little less than the depth of the valley at that point. According to estimates made on the ground and borne out by the map, this thickness appears to have been between 100 and 150 feet. On a grade of about 12 per cent, therefore, *névé* must attain a thickness of at least 125 feet in order that it may have motion. While undoubtedly the minimum thickness must vary inversely with the percentage of the grade, it is impossible to ascertain the law of its variation without a number of additional measurements on valleys of different grades. For this, however, there was no opportunity in the Bighorn Mountains. There is good reason to believe that the influence of the grade is inconsiderable; the sliding of the lowest layers of the glacier over its bed is really only a subordinate feature of its motion, and it is probably influenced more by the amount of ground moraine present than by the grade.

All the evidence obtained in this region, however, leads unavoidably to the conclusion that the only factor which determines the location of the "bergschrund" in any valley is the depth of the *névé*. The cause of glacial motion, therefore, is to be sought in the weight of the ice mass. That it acts independently of the temperature of the air is demonstrated by the fact that "bergschruns" open at all elevations and in the coldest climates. How glacial motion itself is effected, what processes are involved in it, and how it may be accelerated by thaw, are inquiries beyond the scope of this paper.

THE ESMERALDA FORMATION, A FRESH-WATER LAKE DEPOSIT

BY

H. W. TURNER

WITH A DESCRIPTION OF THE FOSSIL PLANTS, BY F. H. KNOWLTON
AND OF A FOSSIL FISH, BY F. A. LUCAS

CONTENTS.

	Page.
General description of the region.....	197
Character of the beds.....	198
Areal distribution of the beds.....	198
Thickness of the beds.....	199
Details of the sections.....	202
Age of the lake beds.....	203
Relation of the lake beds to the lavas of the region.....	205
Vein deposits of the formation.....	206
Economic deposits of the formation.....	206
Coal.....	206
Sulphur.....	207
FOSSIL PLANTS OF THE ESMERALDA FORMATION, BY F. H. KNOWLTON.....	209
Introduction.....	209
Descriptions of species.....	210
Conclusions.....	219
DESCRIPTION OF A NEW SPECIES OF FOSSIL FISH FROM THE ESMERALDA FORMATION, BY F. A. LUCAS.....	225

ILLUSTRATIONS.

	Page.
PLATE XXIV. Map showing the areal distribution of the Esmeralda formation.	198
XXV. A, Contorted sandstones and shales at the coal mines; B, Lake beds east of Clayton Valley	200
XXVI. Lake beds north of the Cave Spring road, at the west base of the Silver Peak Range	202
XXVII. Lake beds and overlying rhyolitic tuff on the south side of the white cone 3 miles northwest of Cave Spring	204
XXVIII. Lacustral marls in ravine south of the Emigrant road at the east base of the Silver Peak Range.....	206
XXIX. The Monocline, showing basalt capping pumice and lake beds.	208
XXX. Plants from the Esmeralda formation: <i>Gleichenia?</i> , <i>Dryopteris?</i> , <i>Salix</i> , <i>Cinchonidiuna?</i> , <i>Quercus</i> , <i>Rhus?</i> , <i>Spathyema?</i> , <i>Chrysobalanus</i> , <i>Cercis</i> , and <i>Ficus</i>	222
XXXI. Fossil fish from the Esmeralda formation (<i>Leuciscus turneri</i>)...	224
FIG. 5. Section of the Esmeralda formation	199

THE ESMERALDA FORMATION, A FRESH-WATER LAKE DEPOSIT.

By H. W. TURNER.

GENERAL DESCRIPTION OF THE REGION.

The deposits that have been designated the Esmeralda formation lie in the Silver Peak¹ quadrangle in western Nevada, near the California line. The scenery is typical of the Great Basin, isolated ranges lying between broad valleys, many of which are of the nature of sinks. In the lowest part of most of the valleys are playas, and forming an intermediate zone between the playas and the ridges are detrital slopes, often of vast extent. The configuration of the country is in the main due to differential uplift and subsidence, and the valleys are thus chiefly of orographic origin.² Such a series of displacements must have been accompanied by normal faulting, and scarps originating in this way are to be seen in the region. In general the main faults trend north and south and east and west. Subsequent erosion has greatly modified the shapes of the ridges and partly filled the valleys with detritus.

In Middle Tertiary time much of the Silver Peak Range did not exist, and the remainder probably formed low ridges. Over a portion of its present site was a broad basin occupied by Lake Esmeralda. The deposits of this lake underlie the valleys and form foothill areas and arch up over the central part of the Silver Peak Range, showing these mountains to have originated in late Tertiary or post-Tertiary time. The deposits of Lake Esmeralda contain at some points an abundance of fossil fish and of dicotyledonous and other plants. The flora is represented by ferns, the fig, oak, willow, sumach, and soapberry, and includes tree trunks 6 to 8 feet in diameter, showing that the climate has undergone a great change since Tertiary time. From a well-watered region it has become an arid one in which there are no running streams.

With the exception of certain gneisses of doubtful age, the oldest rocks of this district are sediments of Lower Cambrian age, the Middle

¹ Am. Geologist, March, 1900, Vol. XXV, p. 168.

² Many of the sinks and lake basins are virtually rock basins surrounded by rocks older than the desert detritus. That such depressions could not be formed by ordinary erosion seems clear.

Cambrian and Silurian being also represented. All of these Paleozoic rocks are rich in fossils, which are often well preserved.

Volcanic activity began in this region in early Paleozoic time. After these first flows of acid lavas the volcanic forces appear to have been quiescent for a very long period. During and subsequent to the deposition of the lake beds, there were great rhyolitic and andesitic eruptions, followed probably in Pliocene time by eruptions of pumice and basalt. This disturbance continued into the Pleistocene, at one point building up a crater which still retains its original outlines.

CHARACTER OF THE BEDS.

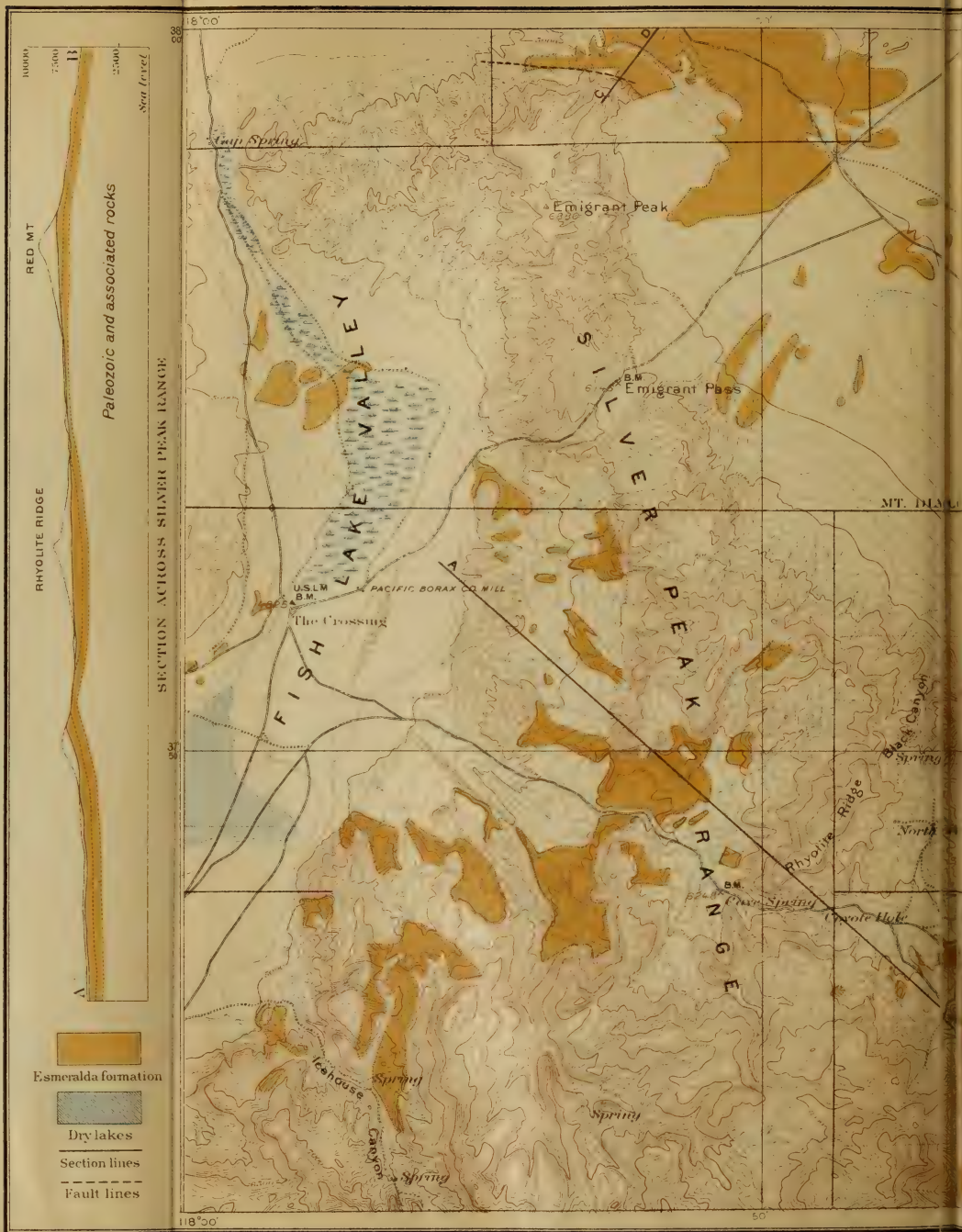
The fresh-water deposits treated of in this paper may be designated the Esmeralda formation, the name being taken from the county in which they occur. The beds are composed of sandstones, shales, and lacustral marls, with local developments of breccia and conglomerate on a large scale. The first published notice of these Tertiary lake beds appears to be that of the mining engineer, Mr. M. A. Knapp, describing particularly the coal deposits¹ occurring in the beds at the north end of the Silver Peak Range. Mr. Knapp collected some molluscan remains near the coal beds, and these were examined by Dr. J. C. Merriam, of the University of California, who considered the shells indicative of fresh water, and possibly Miocene in age.

AREAL DISTRIBUTION OF THE BEDS.

On the accompanying areal map (Pl. XXIV) of the central and northern parts of the Silver Peak quadrangle the distribution of the exposed portions of the Esmeralda formation is shown. In the southern part of the quadrangle the beds are visible at only a few points and undoubtedly are mostly wanting. There are older rocks at the surface nearly everywhere in the Palmetto Mountains and the southern part of the Silver Peak Range. The lake beds undoubtedly underlie the later deposits of Clayton Valley, of the southern part of Big Smoky Valley, and of the northern part of Fish Lake Valley. They are also reported to have been struck in a well bored at Columbus, at the west side of the valley of that name, which lies just north of Silver Peak Range. It is probable that they underlie the Columbus Marsh. They certainly extend north of the Silver Peak quadrangle in Big Smoky Valley. As far as present evidence goes, within the limits of the Silver Peak region the basin containing Lake Esmeralda was bounded on the south by the Palmetto Mountains at the south end

¹ The coal fields of Esmeralda County, Nevada: Mining and Scientific Press, San Francisco, Vol. LXXIV, 1897, p. 133.

It might be noted, however, that fossil fishes from this formation were collected previously by J. E. Clayton and W. P. Blake, but no description of these fossils appears to be in print. *Proc. California Acad. Sci.*, Vol. III, 1866, p. 306.



Topography by W T Griswold

NORTH HALF OF SILVER
SHOWING AREAS OF THE



of Clayton Valley, on the east by the Montezuma Mountains, and on the west by the Inyo Mountains, the northern limit being entirely unknown. Moreover, this basin may easily have connected through the depression north of Lone Mountain with the Ralston Desert basin, which lies east of the Montezuma Mountains. The beds arch up over the central part of Silver Peak Range, reaching an altitude of 7,000 feet at Red Mountain. It is therefore clear that this portion of the range did not exist in Tertiary time, and that its site was a portion of the lake basin extending from the Inyo Mountains on the west to the Montezuma Mountains on the east. It is also clear that this portion of the range was uplifted in post-Esmeralda time. The highest part of the Silver Peak Range attains an altitude of 9,500 feet, but the highest summits are made up of Tertiary lavas of later age than the lake beds.

THICKNESS OF THE BEDS.

No continuous section of the entire formation was found, but an attempt was made to estimate the approximate thickness of the beds. They dip nearly everywhere at angles varying from 5° to 60° from the horizontal and are broken by numerous small faults, so that often a layer followed along the strike is found to offset from 10 to 100 feet or more every few hundred feet. However, in the section at the coal mine and in the zigzag section of the beds east of the south end of Big Smoky Valley, all of the sections being run at approximately right angles to the strike of the beds, no evidence of repetition by faulting or folding was found, and the estimate may therefore be taken as having an approximate value, subject to later revision when better sections of the formation are found elsewhere.

Section A-B.—The base of the series appears to be the sandstone

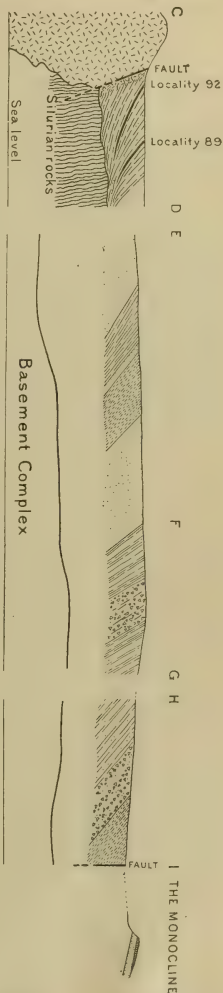


FIG. 5.—Section of the Esmeralda formation.

shown in section A-B (Pl. XXIV) across the Silver Peak Range through Red Mountain, on the east slope of which the sandstones attain a thickness of perhaps 2,000 feet. In a gulch three-fourths of a mile north of the summit of Red Mountain there are very abundant casts of a *Unio* which is specifically undeterminable. Lower down on the east slope are Carbonaceous shales which have been prospected for coal. Near these coal beds Mr. J. D. Reed found some impressions of leaves of marsh plants and bones of fish.

Section C-D.—The Red Mountain series is presumably the same horizon as that in which the coal beds occur at the north base of the Silver Peak Range. Here section C-D was measured, and this section is assumed to represent the base of the formation in the Silver Peak region and to be practically a repetition of A-B. In this section the beds dip from 20° to 45°, usually to the east of north, the average dip being taken as 25°. We have here a high ridge composed of rhyolite and rhyolitic tuff, the north face of which appears to be a fault scarp, as shown by the displacement and contortion of the lake beds where they abut against it, and by the intrusion, along the line of faulting, of basaltic dikes. At some points west of the line of the section the lake beds stand in a vertical position. Mr. Knapp, who figured a section to the west of C-D, recognized the fault. He states that the fault line lies along the north base of the range, dipping about 75° N., and that it shows at the coal mines as a 30-foot clay gouge between the volcanic rocks and the shales. Pl. XXV, A, represents the contorted coal beds near the fault zone west of the gulch in which the chief coal prospects are located. Fig. 5 shows graphically the sections described below:

Section of the Esmeralda formation.

	Feet.
Section C-D, at the coal mines: Just north of the rhyolite fault scarp sandstones and shales, contorted or dipping irregularly.....	250
Coal seam, immediately overlying which is a bed of shale containing leaves No. 92, mostly ferns.	
Sandstones and shales, with a layer containing very abundant fossil gastropods.....	900
Sandstone with some shale.....	1,100

In this last horizon are contained the fossil leaves No. 89, together with some shells and fish bones. The leaf layers afforded most of the leaves described by Professor Knowlton. There were also very abundant layers containing the remains of marsh grasses. The section ends at the north edge of the quadrangle, but the beds continue to the northeast, toward the Monte Cristo Mountains.

To the east of this section in the same area of the beds are still higher beds, chiefly buff shales, and in one layer of these shales, which is purplish when freshly broken, very abundant and fairly well preserved fossil fish were found. The horizon in which they occur is presumed to be about the same as that in which similar though larger fish were found in section E-F, this hypothesis being based on the relative position of each fish layer above the massive sand-



A. CONTORTED SANDSTONES AND SHALES AT THE COAL MINES.



B. LAKE BEDS EAST OF CLAYTON VALLEY.

stone horizon which forms the top of section C-D and the base of the section E-F, and the sandstone horizon is used as a means of joining sections C-D and E-F. They thus overlap, but due allowance for this has been made in the measurements. Inasmuch as there is no visible connection between the sandstone horizon at D and at E, Big Smoky Valley lying between, the correctness of the estimate of the thickness of the formation evidently depends on the same horizon being represented at these points.

Section E-F: The sandstones, shales, and lacustral marls of the next part of the broken section here described do not contain fossil shells, leaves, or coal, so far as noted, and this lends support to the hypothesis here assumed, that all of the beds east of the south end of Big Smoky Valley are of later age than the beds containing the coal near the base of section C-D. In section E-F the beds dip 10° to 60° SE., the average dip being assumed to be 30° .

Sandstone, shales, and lacustral marls.....	5,200	
Deducting for overlap on section C-D	1,000	
	————	4,200

Above the massive basal sandstone of this section is a layer of rhyolitic pumice, perhaps 200 feet in thickness, and some andesite breccia.

In the middle and upper portion of this series are remains of fishes over a foot long. The sandstones lying above the fish beds contain rhyolitic detritus, and at this horizon are the fine white rhyolitic rocks in which the sulphur deposits noted later occur.

Breccia beds with intercalated layers of sandstone	900	
--	-----	--

Section F-G: The beds of this section dip to the east of south at from 40° to 60° , the average dip being assumed to be 50° .

Sandstones and shales	1,600	
Breccia beds	1,300	
Sandstones and shales	1,300	

At the top of this section is a layer of calcareous tufa in mammillary and thinolitic forms and a thin layer of conglomerate with well-rounded pebbles.

Section H-I: At G the beds are displaced and the next section, H-I, is therefore offset to a point to the southwest, beginning, as near as could be estimated, at the same beds as at G. The average dip of this section is 30° to the southeast.

Sandstones and shales	800	
Breccia beds	1,000	
Lacustral marls	1,300	

At I there is supposed to be a line of faulting, for here is a bed of brown basaltic tuff with a nearly vertical dip, and the same bed of brown tuff may be noted on the north face of the Monocline, that lies about 2,000 feet south. The Monocline is presumed to be uplifted along this fault line, the present position of the fault scarp to the south of the fault line being due to erosion, the basaltic cap preserving the scarp feature during its recession by protecting the soft underlying beds. The upper beds of this monocline may, therefore, be taken as forming the top of the section.

Monocline section	150	
-------------------------	-----	--

In the section at the Monocline there is at the base white friable sandstone 100 feet, then brown tuff and white pumice 100 feet, and basalt 50 feet. But inasmuch as the brown tuff occurs at I, where there is supposed to be a line of faulting, the lower sandstone of the monocline is presumed to be included in section H-I, and is therefore omitted from the computation. So

far as known there are no lake beds of the Esmeralda formation later in age than the basaltic flows represented by the basalt cap of the Monocline. The section may be said to end here.

Total	14,800
-------------	--------

The thickness of 14,800 feet of beds, as given in this estimate, seems incredible, although it may represent all of Miocene and Pliocene time, inasmuch as all the fossils that have any value in determining the age were found at the base of the formation. The field evidence of the occurrence of the basalt flows of the region, such as that capping the Monocline in Clayton Valley and supposed to represent the top of the section, certainly suggests for them a Pliocene age, for these basalt flows nearly everywhere cap mesas and seem to be the latest of the lavas, excepting only the basaltic eruptions that built up the finely preserved crater in Clayton Valley, which is clearly of Pleistocene age.

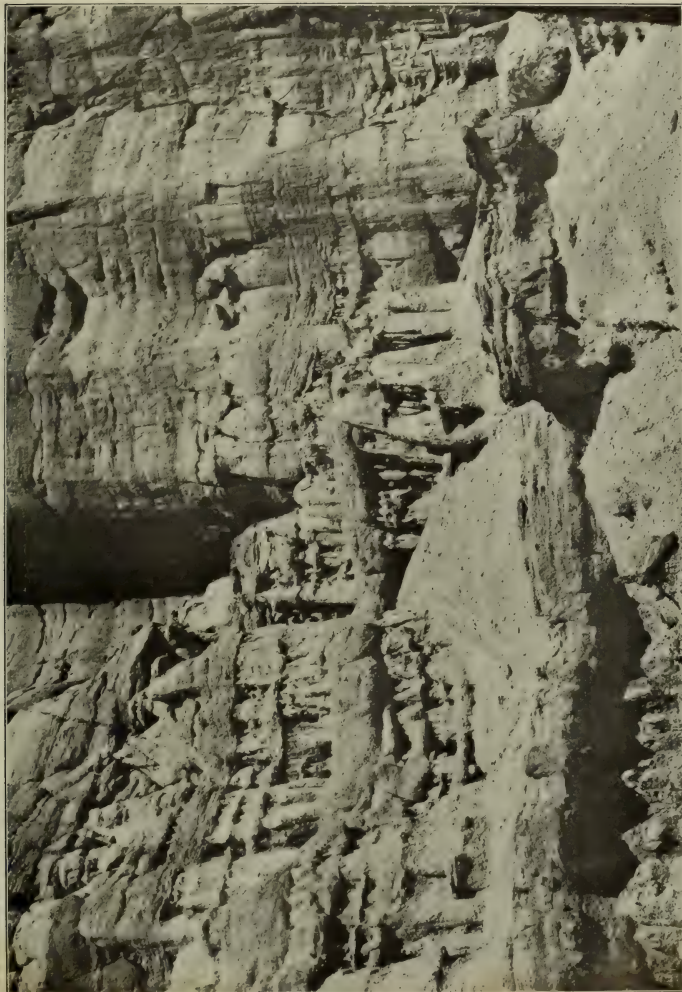
The depth below the surface of the basement complex on which the beds rest, and the angle at which the lake beds rest on this complex, are of course entirely unknown. In all probability the rocks underlying section C-D are vertical slates and cherts of the Palmetto formation (Lower Silurian), since these beds outcrop not far to the west.

DETAILS OF THE SECTIONS.

The calcareous tufa found at G strongly resembles similar deposits found by Professor Russell and others in the Lake Lahontan beds on the shores of Mono Lake. The thickness of the tufa is perhaps 20 feet, and it was not observed elsewhere in the beds. A specimen of the prismatic form of the tufa or thinolite was sent to Prof. E. S. Dana, who was struck with its resemblance to the thinolite of Lake Lahontan. Professor Dana suggests that the original material may have been crystallized aragonite, which has gone over to calcite by paramorphism, regarding this as a more probable origin than that which he formerly suggested,¹ that thinolite is a pseudomorph after a double salt of calcium and sodium. To the south of the road, about three-fourths of a mile west of Cave Spring, is a streak of travertine along the base of a low ridge of tawny sandstone. This appears, however, to be a spring deposit (possibly formed at the same time as the sandstone) and, therefore, of a different nature from the tufa deposits formed from the lake waters. Similar travertine deposits were observed elsewhere, sometimes near or in the lake beds, but some of these are probably of recent origin.

Any one looking at the low hills that lie east and southeast of the south end of Big Smoky Valley will see bare yellow sandstone hills and a large group of low hills and ridges of a dark color. He may at once draw the conclusion that the two sets of hills are composed of

¹ Bull. U. S. Geol. Survey No. 12, 1884, p. 25.



LAKE BEDS NORTH OF THE CAVE SPRING ROAD, AT THE WEST BASE OF THE SILVER PEAK RANGE.

different materials, probably of different ages. A cursory examination of the dark hills would strengthen this conclusion, for they are covered with loose fragments of all the Cambrian and Silurian rocks that comprise the higher ridges to the east. A more careful examination, however, discloses the fact that underneath this loose material there are massive-bedded breccias with thin sandstone layers intercalated, and that this entire series dips conformably with the sandstones of the yellow areas—that is, to the south and southeast. Frequently any one layer of this breccia is composed chiefly of one kind of Paleozoic rock; thus some layers outcrop as reefs of limestone, identical in general appearance to similar reefs in the Paleozoic terranes; other layers are composed chiefly of green Cambrian slate; so that if the broken-up nature of the material were not evident and these reefs were not intercalated with layers of Tertiary sandstone, one might easily, on a cursory inspection, suppose that he had to do with deposits of Paleozoic age. These breccias evidently represent old detrital slopes of Tertiary age, and seem to indicate an uplift or a drier period in the formation of the lake beds, followed again by a depression, as indicated by the fine sediments overlying.

East of the Clayton Valley playa lacustral marls only appear to have been laid down—at least only these upper beds are exposed. They are capped with rhyolitic sandstone, the entire series dipping from 5° to 10° SE. These beds are shown on Pl. XXV, B.

A short but interesting section of the lake beds is to be seen in the wide, steep-sided ravine south of the Emigrant road at the east base of the Silver Peak Range. The lake beds abut abruptly against a wall of rhyolite on the west, and this rhyolite appears to have forced its way up at this point, but it is possible that the contact is one due to faulting. The beds nearest the rhyolite are tern-gray lacustral marls, which weather into softly rounded knolls, some of which are represented on Pl. XXVIII. There is a layer of andesite breccia and one of rhyolitic pumice interbedded in the marls. The breccia contains abundant fragments of silicified wood. Exactly the position in the series that this section occupies was not determined, but the rhyolitic pumice layer may easily be the same as that near the base of section E-F, there being in both cases andesitic breccia near by.

AGE OF THE LAKE BEDS.

The fossil shells, consisting chiefly of gasteropods from near the coal mines, are in about the same horizon as the leaves, and presumably also in about the same horizon as the fresh-water clams (*Unio*) collected north of Red Mountain. All of the fossil shells were referred to Dr. J. C. Merriam, of Berkeley, California, who states:

I find four species of shells in your collection, *Campeloma* sp., *Unio* sp., *Planorbis* like *spectabilis* Meek, and *Ancylus* like *undulatus* Meek. The first three forms resemble

species described from the Eocene of western United States; the last form resembles a species described from supposed Miocene beds. Though I do not regard these few forms as characteristic enough to determine the age of the beds definitely, I should think they might be early Miocene or late Eocene.

Mr. J. E. Spurr collected some poorly preserved shells from the Esmeralda formation about 10 miles southeast of Columbus. These were referred to Dr. W. H. Dall, who was unable to identify any of them with certainty. He found a bivalve that may be a *Sphærium*, and a gasteropod that may be a *Planorbis*. Dr. Dall thought the forms suggested a fresh-water origin.

According to Clarence King¹ *Ancylus undulatus* Meek and two species of *Sphærium* are found in the Truckee beds in the Kawsah Mountains of Nevada, in the fortieth parallel region. The Truckee beds are supposed to be of the same age as the John Day beds of Oregon, and King refers the Truckee group to the Miocene, chiefly on the basis of the vertebrate remains found in the John Day beds. Later investigations may therefore correlate the Esmeralda formation with the Truckee beds of Pah Ute Lake. Moreover, the John Day beds are said to antedate the basaltic eruptions, and this is likewise the case with the Esmeralda deposits. The collection of fossil fish was obtained chiefly from a single layer in the buff shales, $3\frac{1}{2}$ miles due east of the coal mines. It comprises a large number of individuals, many of them fairly well preserved. Prof. F. A. Lucas, of the United States National Museum, regards them all as forms of one species of *Leuciscus*, not differing greatly from living forms.

The fossil leaves were referred to Prof. F. H. Knowlton. Being mostly new species they are of little value in determining age, but from the resemblance of many of them to living forms Professor Knowlton regards them as of a comparatively recent age. One species, *Salix angusta*, is found in the Green River group (Eocene). Another species, a *Cinchonidium*, is allied to a form in the Fort Union group (Eocene?). The fossil fish, which, according to Professor Lucas, resembles a modern form, presumably suggests a Pliocene rather than a Miocene age, but being also a new species, like most of the fossil leaves, it is of little value for present purposes in determining age, although valuable for future correlation.

The evidence of the age of the beds as obtained from paleontologic data is thus unsatisfactory, but the resemblance of some species of both mollusks and plants to Eocene forms and the resemblance of several of the plants and of the fish to living forms suggest a Middle Tertiary or Miocene age for the fossil-bearing horizons, yet inasmuch as the fossils come chiefly from near the base of the formation it seems quite probable that the upper beds are of Pliocene age, so that the formation as a whole should be designated Neocene. What may

¹ U. S. Geol. Expl. Fortieth Par., Vol. I, p. 422.



LAKE BEDS AND OVERLYING RHYOLITIC TUFF ON THE SOUTH SIDE OF THE WHITE CONE THREE MILES NORTHWEST OF CAVE SPRING

be regarded as additional evidence of the Miocene age of the basal beds of the series is the indurated character of the sandstones in the ravines north and south of the Cave Spring road on the west side of the Silver Peak Range, and the character of the coal at the base of section C-D. This coal contains more fixed carbon than volatile hydrocarbons, while in the coals of the Tejon formation (Eocene) of California, the volatile hydrocarbons are in excess of the fixed carbon. Since, other things being equal, the older a coal the more fixed carbon it contains, the inference is drawn that these coals are at least pre-Pliocene. This last inference is, however, of doubtful value, inasmuch as in certain instances the same bed has appeared as lignite at one point and as bituminous coal at another.

RELATION OF THE LAKE BEDS TO THE LAVAS OF THE REGION.

What may be regarded as the oldest lavas associated with the lake beds are narrow dikes and thin intruded sheets of andesite, usually much altered, in the hardened sandstones of the gulches south of the Cave Spring road at the west base of the Silver Peak Range. This inference is drawn from the altered character of the intrusions, the date of the intrusions being unknown. At the locality near the coal mines, where leaves No. 92 were collected, is a light-gray volcanic layer, rich in biotite, and this layer is interstratified with shale. This clearly indicates an eruption of the age of the inclosing beds. The lava contains numerous crystals, broken or entire, of plagioclase, sanidine, quartz, and biotite, in a groundmass that appears to be a devitrified glass. From the abundance of the plagioclase and biotite, and from the fact that the groundmass has an index of refraction greater than that of balsam, and hence is somewhat basic, this material may be called a dacite.

To the south of the Cave Spring road on the west side of the Silver Peak Range are extensive beds of sandstone and conglomerate, the latter containing abundant pebbles and fragments of rhyolite and of the coarse andesite that caps the neighboring ridges. In this volcanic conglomerate at one point is an intruded sheet of olivine-basalt. Since the basal sandstones here clearly underlie the rhyolites and andesites, it is evident that these conglomerates represent a much later time than do the basal sandstones. Between the period of the deposition of the basal sandstones and the associated conglomerates and the formation of the later conglomerates above noted the main rhyolite and andesite eruptions took place. Nevertheless, there were earlier rhyolitic and andesitic eruptions, as is evidenced by the well-rounded pebbles of these rocks in the conglomerates associated with the basal sandstones. Some of these earlier conglomerate beds dis-

tinctly underlie the massive rhyolite tuffs; for example, those forming the white cone having an altitude of 7,100 feet, 3 miles northwest of Cave Spring, a view of which is presented on Pl. XXVII.

South of the Emigrant road, as already noted, there is a layer of andesite breccia in the lake beds containing fossil wood, and overlying it, perhaps 200 feet, is a layer of rhyolitic pumice. This section is probably higher up than section C-D, which contains the dacite, and very likely, as before indicated, represents the basal part of section E-F. To the east of Big Smoky Valley, and to the north of the zig-zag section E-F-G-H-I, still higher in the series, are extensive beds of conglomerate with well-rounded pebbles. In these conglomerates are layers of white pumice. Finally, we have at the monocline and at other points rhyolitic tuffs and pumice capped by basalt. Very probably the brown tuff in the Monocline is of basaltic origin, but at numerous other points, especially southwest of Silver Peak, there are extensive beds of rhyolitic pumice and tuff overlying lake beds and capped by basalt. There is also at the Monocline a layer of white pumice between the brown tuff and the basalt cap. The basaltic eruptions are regarded as the closing event in the history of the deposition of the sediments of Lake Esmeralda.

VEIN DEPOSITS OF THE FORMATION.

In the sandstones exposed in the ravines north and south of the Cave Spring road on the west side of the Silver Peak Range and in the sandstones of the area in which the coal mines occur are frequent white veins following in most cases fault lines. In some instances these contain fragments of the wall rocks. These veins are made up chiefly of calcite, sometimes in part of chalcedony, and some of them contain green coloring matter, apparently of a chloritic nature. The veins dip from 30° to 90° from horizontality and are from half an inch to 2 feet in thickness.

ECONOMIC DEPOSITS OF THE FORMATION.

COAL.

The chief material of economic value in the lake beds is coal, which forms one or more layers in the sandstone at the north base of the Silver Peak Range. This has been opened by inclines at several points. According to Knapp there are two seams, one 1½ feet and the other 5 feet thick. He supposes these beds to extend north under Columbus Valley, which is highly probable. They should, however, be found much nearer the surface in the low divide separating Columbus and Big Smoky valleys, where at some points the dip of the strata is only 5°. The coal prospects examined by Knapp were



LACUSTRAL MARLS IN RAVINE SOUTH OF THE EMIGRANT ROAD, AT THE EAST BASE OF THE SILVER PEAK RANGE.

probably those near the head of the gulch in which most of the workings lie, and these are near the zone of faulting previously referred to. The inclines being worked at the time of the writer's visit (1899) are farther north, where the thickness of the single layer of coal is 10 feet, the dip being 20° to 30° NE. This coal may be designated lignite. From the analyses given below it will be noted that when burned it leaves a large amount of ash. This is said to be the chief objection raised against it by the engineers of the Central Pacific Railroad, who made a locomotive test.

Analyses of coal from the Esmeralda formation.

	Elder-Morgan mine. ^a	Knapp's average.
	<i>Per cent.</i>	<i>Per cent.</i>
Moisture	3.53	31.5
Volatile combustible material	31.71	
Fixed carbon	35.95	38.5
Ash	28.81	30
	100.00	100
Sulphur	1.05	.....

^a Dr. Hillebrand notes that the ash is light gray and contains some sulphate. The coke is coherent, but not much swelled.

The first analysis, by Dr. W. F. Hillebrand, was made in the chemical laboratory of the United States Geological Survey, the coal being a sample from the Elder-Morgan mine. The second analysis is that given by Knapp as the average analysis.

While it is probable that this coal will be of local value for stationary engines, house use, etc., it is not likely to be used on the railroads on account of the high percentage of ash, requiring the frequent cleaning of the ash boxes. It is said to be a good coking coal, but its value in this respect, so far as the writer is aware, has not been determined by a practical test. The chief difficulty in mining it at present is that for the larger part of the year there is no drinking water near the mines and no timber. Since the layers probably underlie the district north and northeast of the outcrops at the mines, the quantity of coal available is very likely large.

SULPHUR.

To the east of the south end of Big Smoky Valley, in a fine-grained, white, decomposed material, perhaps a rhyolitic tuff or silt, is a deposit of sulphur, which was at one time worked. The locality is just east of the Reese River road, 2 miles north of bench mark 4996. The

white rock is intersected by fractures and joints, and the sulphur seems to have come up as vapor from below and to have been deposited by sublimation in the fractures. Most of the sulphur is yellow, and much of it shows crystal faces. There is also an efflorescence of alum in seams of the rock in the old cuts. Another sulphur prospect lies just northeast, across the gulch. Here some sulphur crystals are an inch in diameter.



THE MONOCLINE, SHOWING BASALT CAPPING, PUMICE, AND LAKE BEDS.

FOSSIL PLANTS OF THE ESMERALDA FORMATION.

By F. H. KNOWLTON.

INTRODUCTION.

In July, 1899, Mr. H. W. Turner, of the United States Geological Survey, sent me a small box containing a few fossil leaves collected near Silver Peak, Esmeralda County, Nevada. A hasty examination showed much of interest, and Mr. Turner was requested to secure as large a collection as possible from the locality. Later in the season he sent in an additional box of material, which has furnished the basis for the following report.

The beds containing these plants, to which Mr. Turner has given the name Esmeralda formation,¹ occur at the northern end of the Silver Peak Range, in Esmeralda County, Nevada. They consist of sandstones and shales having an approximate thickness of 2,000 feet, and were laid down in part at least in fresh-water lakes. These beds contain extensive deposits of coal, and the fossil remains occur in close proximity to the coal seams and embrace, besides the plants, a few fresh-water shells and fish remains. The shells have been studied by Dr. J. C. Merriam, and the fish remains by Mr. F. A. Lucas, of the United States National Museum, whose report follows this.

The exact localities for the fossil plants are as follows:

Number 92: Immediately overlying a 10-foot coal seam, 3.8 km. northeast of Emigrant Peak, at the northern base of the Silver Peak Range, Esmeralda County, Nevada.

Number 89: Sandy shale 4.5 km. northeast of Emigrant Peak, at the northern base of the Silver Peak Range, Esmeralda County, Nevada. This series overlies No. 92.

At Mr. Turner's request I made a very hasty preliminary examination of this collection and prepared a brief report, a portion of which was printed in the paper cited. At that time I mentioned the presence of two previously known forms, viz, *Rhus fraterna* Lx., and *Hecquericifolia* Lx., but a careful examination has convinced me

¹Am. Geologist, March, 1900, Vol. XXV, p. 168.

that, while close to these species, the forms in question are sufficiently distinct to warrant their being described as new to science. While the plants of this little collection have in general a familiar facies, they are found to differ in a greater or less degree from described forms and consequently have been regarded as new. This florula, as at present constituted, embraces 14 forms, which are described below.

DESCRIPTIONS OF SPECIES.

GLEICHENIA? OBSCURA n. sp.

(Pl. XXX, figs. 1-4.)

Outline of frond unknown; pinnae linear-lanceolate in shape, cut nearly or quite to the rachis into alternate or opposite, deltoid, acute, slightly scythe-shaped entire segments; nervation obscure, but with a midvein which is near the lower margin and few apparently once-forking very slender veins; fructification unknown.

This interesting form is represented in the collection by a considerable number of fragments. It is impossible to make out the original form of the frond, as none but detached fragments of pinnae are found, but it was probably a compound frond. The pinnae are narrowly lanceolate, the longest fragments preserved being only about 2 cm. in length. The width varies from 5 to 8 mm. Neither base nor apex is preserved. As stated in the diagnosis, the nervation is obscure, but it consists of a thin midvein, which is located much nearer the lower margin, and of a few apparently once-forking veins. While the fructification is not preserved, there is some slight indication that it consisted of a few minute sori on either side of the midvein and about midway between it and the margin, but this is too obscure to be of value.

I have hesitated to describe this form, as the material is so very fragmentary that its size and relationship can not be made out with anything like satisfaction, and especially have I hesitated to refer it to *Gleichenia*. It, however, agrees so exactly in size and shape with *G. polypodioides* Sm., of the Cape of Good Hope, that it seems unwise to separate them generically. The nerves in the living species are not forked, while in the fossil they seem to be once forked; but this is obscure.

This form is also much like a number of other living ferns, as, for instance, *Polypodium serrulatum* Mett., a species living in the Antilles, Mexico, and South America. It is, however, closer to the species of *Gleichenia* above mentioned, and I have tentatively referred it to this genus. It lacks the characteristic branching usually observed in the fronds of this genus and may not belong to it.

Locality: Northern base of Silver Peak Range, 3.8 km. northeast of Emigrant Peak.

DRYOPTERIS? GLEICHENOIDES n. sp.

(Pl. XXX, figs. 5-7.)

Outline of frond unknown; pinna lanceolate-deltoid in outline, cut to about one-half the distance to the rachis into ovate, obtuse, entire, slightly scythe-shaped segments; midvein thin, in the middle of each segment or pinnule; lateral veins about 5 pairs in each pinnule, each once forked in the middle; fruit unknown.

The collection contains a large number of fragments that appear to belong to this form. They appear to be pinnae from a large frond, but there are none connected and hence there is no indication of the size and shape of the frond as a whole. The fragments preserved are about 2 to 2.5 cm. in length and about 1 cm. in width. They are well shown in the drawings.

I am very uncertain as to the proper generic reference of this form, as there is no trace of fruit preserved. It is found not only in the same beds as the last-mentioned form, but often preserved on the same pieces of matrix, and was at first supposed to represent a variation of it, but after a careful examination I am not certain of this. Both of the forms appear to vary considerably, yet they do not actually seem to join, and I have kept them separate, even generically.

Locality: Northern base of Silver Peak Range, 3.8 km. northeast of Emigrant Peak.

SPATHYEMA ? NEVADENSIS n. sp.

(Pl. XXX, figs. 17, 18.)

Spadix globose or oblong; perianth succulent, circular, or by compression elliptical or irregularly quadrangular in shape; ovary immersed, leaving a deep pit.

I am very uncertain as to the fossil here described and figured. It appears to have been a globose or club-shaped spadix with numerous ovaries immersed in thickened portions of its substance. Each ovary now appears as a pit sunk in fleshy segments of the spadix, which are elliptical, nearly circular, or irregularly quadrangular in shape and apparently surrounded by a thicker rim or wall. The upper or outer surface of each is minutely papillose or roughened. These thickened portions vary much in size, the smallest being hardly more than 1 mm. in diameter, while the largest are fully 8 mm. across. This difference in size is perhaps due to their being in different stages of development.

This curious organism was at first supposed to belong to the animal kingdom, but it has been shown to a number of zoologists, and all are positive it can not be of an animal nature. It was then shown to several botanists, and the conclusion was reached that it was an aroid

spadix. When compared with the spadix of *Spathyema* (*Symplocarpus*) *fiatida*, it is seen that there are numerous points in common, and, while it does not agree in every particular, it is certainly very suggestive of this, and I have ventured so to place it. It is associated on the matrix with fragments of sedge-like plants, which would seem to indicate that it was a denizen of moist or swampy localities, such as *Spathyema* is known to delight in. More and better material will be necessary before its exact status can be settled.

Locality: Northern base of Silver Peak Range, 3.8 km. northeast of Emigrant Peak.

UNKNOWN PLANT.

(Plate XXX, figs. 16, 24, 25.)

The collection contains a number of very curious plants, three of the best of which are here figured. They are associated on the same pieces of matrix as the form described under the name *Spathyema* ? *occidentalis*, and may have some connection with that species; yet the connection, if such there be, is very obscure, and can not be made out with certainty.

They have the appearance of being some sort of a fructification inclosed on all sides by a thin, membranous covering. In shape they are elliptical or elliptical-oblong. The smallest is about 16 mm. long and 10 mm. wide, while the central, apparently fruiting portion is 10 mm. long and about 7 mm. wide. The largest specimen is 22 mm. long and 18 mm. wide. The other specimens approach in size the first one mentioned above.

Locality: Northern base of Silver Peak Range, 3.8 km. northeast of Emigrant Peak.

SALIX ANGUSTA ? AL. Br.

(Pl. XXX, fig. 23.)

The collection contains a single fragment, together with its counterpart, which seems to belong to this species. It is nothing more than a segment out of the middle of a narrowly lanceolate leaf, and has the same nervation as that shown by Lesquereux for the American leaves referred to this form.

Locality: Northern base of the Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

SALIX VACCINIFOLIA n. sp.

(Pl. XXX, figs. 8, 20.)

Leaves small, subcoriaceous in texture, lanceolate in outline, about equally narrowed to both base and apex; margin perfectly entire; petiole short, stout; midrib strong below, becoming much thinner

above; secondaries numerous, close, alternate or subopposite, at an angle of about 50° , apparently camptodrome; finer nervation not preserved.

This little species is represented by several more or less perfect leaves, two of the best of which are here figured. It is lanceolate-acuminate in shape, about 2.5 to 5.5 cm. in length and 6 to 13 mm. in width. The petiole is only about 2 mm. in length.

This species appears to be quite closely allied to the living *Salix flurialis* Nutt. (*S. longifolia* Muhl.), a species abundant throughout most of the region west of the Mississippi. It is not, however, like what may be called the typical form, with long narrow leaves, but is similar to certain of the smaller, relatively broader-leaved forms. It does not appear to approach very closely to any previously described fossil North American species.

Locality: Northern base of Silver Peak Range, 3.8 and 4.5 km. northeast of Emigrant Peak.

SALIX sp.

(Pl. XXX, fig. 13.)

Leaves of firm texture, narrowly lanceolate in shape, base destroyed, apex apparently long-acuminate; margin obscurely serrate above; midrib rather slender; secondaries few, alternate, at an acute angle, much arching upward, running along near the margin for a considerable distance, apparently sending weak branches on the outside to the marginal teeth; finer nervation obscure, apparently broken.

This form is represented by the single broken example figured, which lacks both base and apex. It is narrowly lanceolate, the portion preserved being about 7 cm. in length and 13 mm. in width at the broadest point, which is apparently about the middle of the leaf. The full length when perfect was probably about 9 or 10 cm.

While this species is clearly a *Salix* and allied to a number of described forms, I have hesitated to name it on this scanty material. It has much the shape and size of *Salix angusta* Al. Br.,¹ but appears to differ in being obscurely toothed above. The teeth, however, are to be made out with difficulty, and as there is only one specimen, together with its counterpart, it seems best not to give it a name.

Locality: Northern base of Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

SALIX? sp.

(Pl. XXX, fig. 14.)

Leaves of firm texture, elliptical-lanceolate in outline, about equally narrowed to both base and apex; petiole long, rather strong for the

¹ Cret. and Tert. Fl., 1884, p. 247, Pl. LV, fig. 6.

size of the blade; margin perfectly entire; midrib moderately strong; secondaries thin, about 7 or 8 pairs, alternate, at an angle of about 45°, very slightly arching upward; remainder of nervation obsolete.

The collection contains several leaves that appear to be identical, one of the best of which is figured. They are well preserved as regards outline, but the nervation is nearly obsolete. These leaves are rather broadly lanceolate in outline, being 4 to 4.5 cm. in length and 11 to 13 mm. in width. The petiole preserved in only one instance is about 1 cm. long.

These leaves appear to belong to *Salix*, but the finer nervation is so obscure that it is impossible to determine them with satisfaction. I have therefore placed them under *Salix*, but have not attempted to point out relationships.

Locality: Northern base of the Silver Peak Range, 3.8 km. northeast of Emigrant Peak.

QUERCUS TURNERI n. sp.

(Pl. XXX, fig. 21.)

Leaf evidently thick and coriaceous, elongated, elliptical in general outline, truncate and oblique at base, obtuse at apex; margin provided with numerous large rather obtuse teeth, separated by shallow, mainly rounded sinuses; petiole slender; midrib slender; secondaries about 12 pairs, slender, irregular, both opposite and alternate, emerging at various but mostly at low angles, passing to the marginal teeth, occasionally forking and the branches entering the teeth; nervilles numerous, all broken; finer nervation forming numerous quadrangular areas.

This species is represented by the example figured and its counterpart and several smaller fragments. It is narrowly elliptical in outline, being about 4.5 cm. long and 2 cm. wide in the middle. The base is truncate or square on one side and oblique or wedge-shaped on the other, while the apex is quite obtuse. The margin is provided with numerous large low teeth, which are separated by shallow sinuses. The nervation is beautifully preserved, consisting of a rather slender midrib and about 12 pairs of irregular secondaries and numerous broken nervilles. The finer nervation forms numerous rather large irregularly quadrangular areas.

This species is rather closely allied to certain living and fossil forms. Thus it is similar in shape to *Quercus undulata* Torrey, a species found in the southern Rocky Mountain region, but differs in being much larger and in having a larger number of secondaries. It is also similar to *Q. dumosa polygarpa* Greene, but is perhaps nearest to *Q. turbinella* Greene, a shrubby species of southern California and Arizona, on the borders of the Mohave Desert. The leaves of the latter are much smaller than the one under consideration and have a smaller number of teeth and secondaries, but the finer nervation is the same.

Among fossil species it is very near to *Quercus applegatei* Kn.,¹ from the Miocene of the Cascade Range found near Ashland, Oregon. This differs in being less truncate at base and much more acuminate at apex, and has the more rounded teeth. The finer nervation is similar, but not quite so much broken up.

Locality: Northern base of the Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

QUERCUS ARGENTUM n. sp.

(Pl. XXX, fig. 12.)

Leaf of firm texture, lanceolate in outline, undulate margined and about equally narrowed at both base and apex; petiole short, slender; midrib slender; secondaries about 8 pairs, at irregular distances, alternate, emerging at an angle of about 45° , thin, camptodrome, arching near the margin; nervilles rather few, broken; finer nervation producing larger, irregularly quadrangular areas.

This little leaf, the only one found, is lanceolate with irregularly undulate margins. As preserved it is 4.25 cm. in length exclusive of the petiole, which is 6 mm. long. The nervation consists of about 8 pairs of alternate, irregular secondaries and a loosely areolated finer network, which is unmistakably quercoid in appearance.

This species does not appear to be very closely related to any species either living or fossil with which I am familiar, yet it seems undoubtedly to belong to *Quercus*, and I have so placed it.

Locality: Northern base of the Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

FICUS LACUSTRIS n. sp.

(Pl. XXX, fig. 26.)

Leaves thick and coriaceous, apparently elliptical in general outline, rounded and very unequal-sided at base (apex destroyed); margin entire; petiole short, very thick; midrib thick, straight; secondaries numerous, alternate, very thin and deeply concealed in the parenchyma, slightly flexuose, the lowest pair arising at the base of the blade, and the one on the broad side of the blade with numerous outside branches which arch just inside the margin and join by broad loops; other secondaries with few outside branches which loop in the same manner; nervilles numerous, irregular, and mainly broken; finer nervation producing irregularly quadrangular areolæ.

The example figured is all that was found of this species and unfortunately this lacks the upper portion. The part preserved is about 6 cm. in length, and was possibly as much longer when living. The widest point is a little more than 4 cm., although it is so unequal-sided

¹ Twentieth Ann. Rept. U. S. Geol. Survey, Part III, p. 42, Pl. I, figs. 6, 7.

that it is not possible to judge accurately of it. The petiole is thick, being 3 mm. in width. The length preserved is 1.5 cm. but in all probability this is not the whole of it.

Locality: Northern base of the Silver Peak Range, 4.5 km. north-east of Emigrant Peak.

CHRYSOBALANUS POLLARDIANA n. sp.

(Pl. XXX, fig. 19.)

Leaf coriaceous in texture, broadly elliptical in outline, slightly heart-shaped at base, rounded and obtuse at apex; petiole short, thick; midrib very thick below, becoming much thinner above; secondaries about 12 pairs, alternate, irregular, very thin, emerging at a low, almost right angle, camptodrome, arching well inside the margin and joining the one next above, with a series of small loops outside; nervilles very thin, all broken; finer nervation forming very numerous irregularly quadrangular areas.

The example figured is the only one contained in the collection. It is nearly perfect, lacking only a small portion of one side. It is broad-elliptical in shape, being about 5 cm. in length and 4 cm. in width. The petiole is only 2 or 3 mm. in length, although it was possibly a little longer when living. This leaf was clearly very thick and coriaceous and has a very thick midrib, which, however, becomes much thinner above the middle. The secondaries are very thin and nearly at right angles to the midrib, arching some distance inside the margin and passing to the one next above by a series of loops. The finer nervation is beautifully preserved, forming rather large irregularly quadrangular areas.

I have been somewhat in doubt as to the proper generic reference of this finely preserved leaf. At first glance it seems to belong to *Ficus*, being similar in nervation to a number that have been so regarded. It has also considerable resemblance to certain of the larger-leaved species of *Arctostaphylos*, so abundant on the Pacific coast; but while the shape and coriaceous character are the same, the secondaries in all species I have been able to see are at an acute angle of divergence. The leaf before us seems to agree quite closely with the genus *Chrysobalanus*, and I have so considered it. The only species of this genus now living in the United States is *C. icaco* L., which is confined to southern Florida. This species is also widely distributed in the West Indies, Mexico, and Central America.

I take pleasure in naming this fossil species in honor of Mr. Charles Louis Pollard, of the United States National Museum, who suggested its probable relationship to *Chrysobalanus*.

Locality: Northern base of the Silver Peak Range, 4.5 km. north-east of Emigrant Peak.

CERCIS ? NEVADENSIS n. sp.

(Pl. XXX, fig. 23.)

Leaf membranous, outline uncertain but apparently circular or approximately so, regularly rounded at base; margin entire; petiole very long and slender; nervation palmately five-ribbed from the apex of the petiole; midrib slightly strongest, with a number of alternate branches in the upper part; lateral ribs slightly weaker, the inner with four or five branches on the outside, all camptodrome and arching just inside the margin; lowest pair of ribs with a few loops on the lower side; nervilles few, irregular, and much broken; finer nervation producing large irregular areas.

The fragment figured is practically all of this form in the collection. As may be seen by the figure, it represents only the lower portion of the blade. The outline can not be determined, although it seems to have been approximately circular. The base is regularly rounded and the margin perfectly entire. The petiole was very long and slender for the apparent size of the leaf, being 2.75 cm. in length and evidently not all preserved. The nervation is well shown in the figure, being palmately five-ribbed.

The specimen is so fragmentary that it is quite impossible to make out all the characters, yet, as far as can be noted, it seems to approach closest to *Cercis*. This genus at present embraces about five species, natives of North America, Europe, and temperate Asia. In all the living species the base of the leaves is much more heart-shaped than is the fossil under consideration, and usually there are seven ribs. Occasionally, however, leaves may be found that have only five ribs and the blade somewhat less heart-shaped. This is especially the case with *C. chinensis* and occasionally in leaves of *C. occidentalis* Nutt., from the Pacific coast. The disposition of the ribs and their secondary branches is practically identical in both living and the present fossil species.

Thus far three fossil species of *Cercis* have been described from this country, as follows: *C. parvifolia* Lx.,¹ from Florissant, Colorado; *C. truncata* Lx.,² from the Bad Lands of Dakota, and *C. borealis* Newb.,³ from the Fort Union beds near the mouth of the Yellowstone River, Montana. Our leaf seems to be very close indeed to *C. parvifolia*, but differs in being much larger and in having a much longer, more slender petiole. *Cercis truncata* has never been figured, but it is described as exactly similar in form and nervation to the preceding species, differing only in being very much larger and more pointed.

¹ Cret. and Tert. Fl., p. 201, Pl. XXXI, figs. 5-7.

² Op. cit., p. 237.

³ Proc. U. S. Nat. Mus., Vol. V, p. 510.

Cercis borealis has never been figured and the description is not full enough to make out its characters with certainty.

As already stated, the form under consideration agrees most closely with *C. parvifolia* and may be identical, but as its true shape can not be made out, I have ventured to give it a new name pending the discovery of new material.

Locality: Northern base of the Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

CINCHONIDIUM ? TURNERI n. sp.

(Pl. XXX, figs. 9-11.)

Leaves of fine texture, long-elliptical in outline, about equally rounded to both base and apex; strongly unequal sided at base; margin perfectly entire; petiole long, strong, and apparently slightly margined; nervation obscure, consisting of about two pairs of alternate, thin, irregular secondaries at an angle of about 45°; nervilles parallel, mainly percurrent, though often broken; finer nervation forming rather large quadrangular areas.

This species is represented in the collection by several examples, three of the best being here figured. They appear to have been thickish leaves, rather long, elliptical in shape with abruptly rounded and strongly unequal-sided base. The length is 3.5 to 4 cm. and the width about 2 cm. The petiole is 8 to 13 mm. long and apparently marginal. The nervation is obscure, but is well shown in the figures.

This species has considerable resemblance to the genus *Sapindus*, but the petiole is longer and thicker than is usual in this genus, and it seems to approach most closely to *Cinchonidium*. It appears to be allied to *C. ovale* Lx.,¹ which, however, differs specifically in having a shorter petiole and a not so regularly elliptical form. But none of these specimens are very well preserved, especially as regards the finer nervation, and they are referred tentatively to this genus.

Locality: Northern base of Silver Peak Range, 3.8 and 4.5 km. northeast of Emigrant Peak.

RHUS ? NEVADENSIS n. sp.

(Pl. XXX, fig. 15.)

Leaflet subcoriaceous, elliptical-obovate in shape, rather obtuse above, narrowed below to a narrowly wedge-shaped base; petiole very long and slender; margin with few remote low and rather obtuse teeth above the middle of the blade; midrib slender, straight; nervation obscure, but apparently with several pairs of secondaries at an acute

¹ Cret. and Tert. Pl., p. 229, Pl. XLVII, fig. 9.

angle, and apparently terminating in the marginal teeth; remainder of nervation not discernible.

The figured specimen is about 3 cm. in length exclusive of the petiole and 1.25 cm. wide, while the petiole is nearly 1 cm. in length. The outline is elliptical-ovate, narrowed below to a wedge-shaped base and an almost winged petiole. The margin is remotely few-toothed from above the middle. The nervation is very obscure, but apparently consists of small pairs of craspedodrome secondaries.

I refer this form to the genus *Rhus* with some hesitation, as it seems unlikely that a leaflet would have a petiole of this length, but it agrees closely with *Rhus fraterna* Lx.,¹ a species found at Florissant, Colorado. In size, outline, and extraordinary length of petiole one specimen agrees perfectly with this, but differs in having a few marginal teeth. The nervation is similar as far as can be made out.

It is doubtful if Lesquereux's species belongs to *Rhus*, but it is so evidently similar to the one under consideration that I do not hesitate to put them in the same genus.

Locality: Northern base of the Silver Peak Range, 4.5 km. northeast of Emigrant Peak.

CONCLUSIONS.

The fossil plants of the Esmeralda formation, as herein enumerated, embrace fourteen forms, all but one of which are regarded as new. This in itself is an unfortunate circumstance, since in determining their bearing on the question of the age of the beds dependence must be placed entirely on their recognized affinities and general facies. Hereafter it is hoped that the species here described may prove of value in fixing the age of other beds in which they may be found.

The only species before recognized is *Salix angusta* Al. Br., a form found in the European Miocene and since recognized in a large number of localities in this country, as the Green River group at Green River Station, Wyoming, and at various places in the Tertiary of Colorado, Wyoming, Montana, California, etc. On account of its wide distribution it is not of great value in fixing clearly the age of beds in which it may be found.

The remaining forms described as new have been found to be referable in most cases to well-known living genera, which would argue for them a comparatively recent age. Thus we have *Chrysobalanus pollardiana*, which is regarded as quite close to the living *C. icaco* L.; *Cercis nevadensis*, perhaps closest to *C. chinensis*, though similar to occasional leaves of *C. occidentalis* of the Pacific coast; *Quercus turneri*, which strongly suggests *Q. turbinella* Greene, a shrubby species of southern California and Arizona; also suggesting *Q. dumosa polycarpa*

¹ Cret. and Tert. Fl., 1884, p. 192, Pl. XLI, figs. 1, 2.

Greene and *Q. undulata* Torrey of the Rocky Mountain region; *Salix vaccinifolia*, undoubtedly allied to *S. fluvialis* Nuttall (*S. longifolia* Muhlenberg), a species common throughout most of the region west of the Mississippi River; *Spathyema* ? *nevadensis*, which is supposed to be related closely to the eastern *S. fetida* (L.) Raf.; and *Gleichenia* ? *obscura*, which is certainly similar to *G. polypodioides* Smith of the Cape of Good Hope.

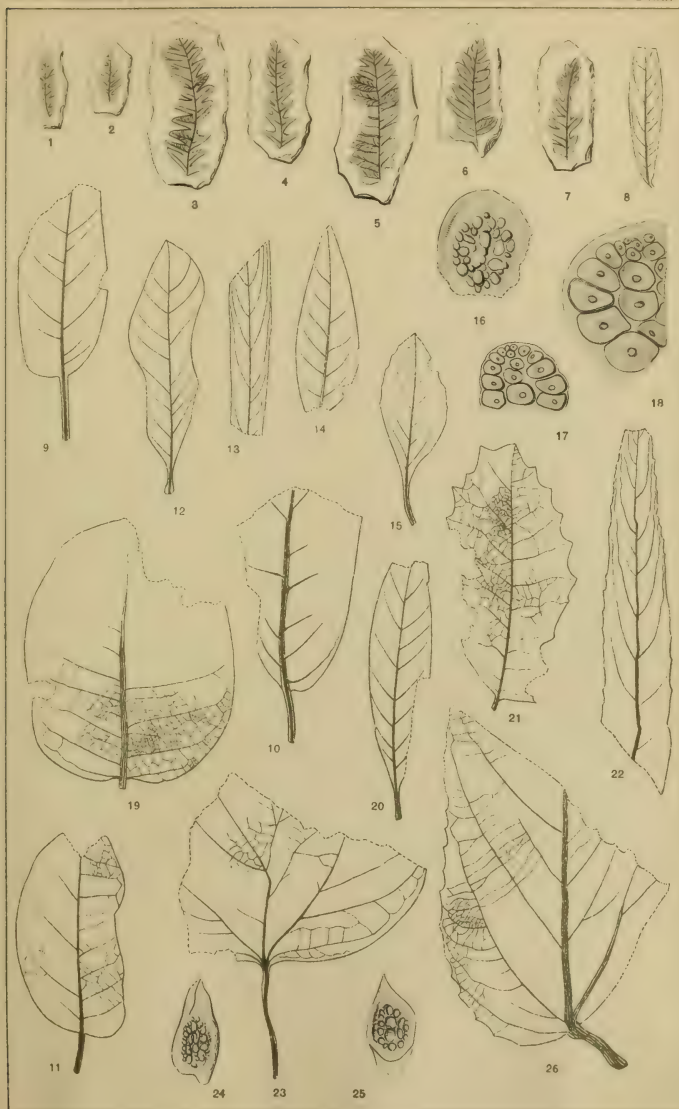
Of the others, the form described as *Salix* sp. is similar to *Salix angusta* and, *Cinchonidium* ? *turneri* is certainly allied generically to *C. ovali* Lesquereux of the Fort Union group.

PLATE XXX.

PLATE XXX.

FOSSIL PLANTS OF THE ESMERALDA FORMATION.

	Page.
Figs. 1-4. <i>Gleichenia</i> ? <i>obscura</i> n. sp.	210
5-7. <i>Dryopteris</i> ? <i>gleichenoides</i> n. sp.	211
8. <i>Salix vacciniifolia</i> n. sp.	212
9-11. <i>Cinchonidium</i> ? <i>turneri</i> n. sp.	218
12. <i>Quercus argentum</i> n. sp.	215
13. <i>Salix</i> sp.	213
14. <i>Salix</i> ? sp.	213
15. <i>Rhus</i> ? <i>nevadensis</i> n. sp.	218
16. Unknown plant.	212
17, 18. <i>Spathyema</i> ? <i>nevadensis</i> n. sp.	211
19. <i>Chrysobalanus pedlariana</i> n. sp.	216
20. <i>Salix vacciniifolia</i> n. sp.	212
21. <i>Quercus turneri</i> n. sp.	214
22. <i>Salix angusta</i> ?	212
23. <i>Cercis</i> ? <i>nevadensis</i> n. sp.	217
24, 25. Unknown plant.	212
26. <i>Ficus laeustris</i> n. sp.	215



PLANTS FROM THE ESMERALDA FORMATION

DESCRIPTION OF A NEW SPECIES OF FOSSIL FISH FROM THE ESMERALDA FORMATION.

By F. A. LUCAS.

The name *Leuciscus turneri* is proposed for a small fish obtained by Mr. H. W. Turner, of the United States Geological Survey, from the Tertiary of the west side of the Big Smoky Valley in the Silver Peak quadrangle, Esmeralda County, Nevada. The type specimen, shown on Pl. XXXI, B, is No. 4302a, Catalogue of Fossil Vertebrates, United States National Museum.

In its general aspect the fish bears a strong resemblance to such small cyprinoids as *Semotilus* and *Leuciscus*, being of much the same general proportions as *Leuciscus lineatus*. The head, as in that species, is a trifle over $3\frac{1}{2}$ in the total length;¹ depth of head, two-thirds of length. There are 19–20 precaudal vertebræ and 17–18 caudal, while *Leuciscus lineatus* and *Semotilus atromaculatus* have, respectively, 20–17 and 21–18. The tail is slightly forked; the lobes are slightly rounded.

The anterior end of dorsal is in line with the anterior end of ventrals, and the posterior end of dorsal is in line with the anterior end of anal. In *Leuciscus* the dorsal is directly over the ventrals and in *Semotilus* the dorsal is behind the ventrals. In both *Leuciscus* and *Semotilus* the anterior end of the anal is a little back of posterior edge of dorsal. The fin rays are as follows: Dorsal, 9; anal, 10; pectoral, 11–12; ventral, 9; caudal, 23. These may be compared with *Leuciscus lineatus* and *Semotilus atromaculatus* as follows:

	D.	A.	P.	V.	C.
<i>Leuciscus turneri</i>	9	10	11	9	23
<i>Leuciscus lineatus</i>	9	8	17	9	23
<i>Semotilus atromaculatus</i>	7	8	14	8	21

¹ According to Jordan and Evermann the head is $4\frac{1}{2}$ in the total length, but this does not accord with the specimen here used for comparison.

The greater number of resemblances are thus seen to be to *Leuciscus lineatus*.

It is quite probable that the very fine rays of the pectorals have failed to make an impression, which would account for the lesser number of rays in *turneri* as compared with others.

Epineurals, epihæmals, and epicentrals are present, but there are no apparent traces of epipleurals, nor should there be if the affinities of this fish are as they have been assumed.

The extreme length of the type specimen, which is of the average size, from tip of nose to center of caudal is $5\frac{1}{8}$ inches; from tip of nose to process of last vertebra, $4\frac{1}{4}$ inches.

With the exception of a few small fragments, it is the impressions of bones that are preserved and not the bones themselves, and this fish is placed with the Cyprinidae on account of its strong general resemblance to that group of fishes, since the pharyngeal teeth have not in any case been found. For the same reason it is kept in the genus *Leuciscus*, as no sufficiently good characters can be assigned to these specimens to warrant the establishment of a new genus.

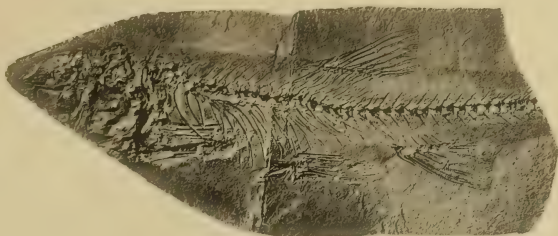
PLATE XXXI.

PLATE XXXI.

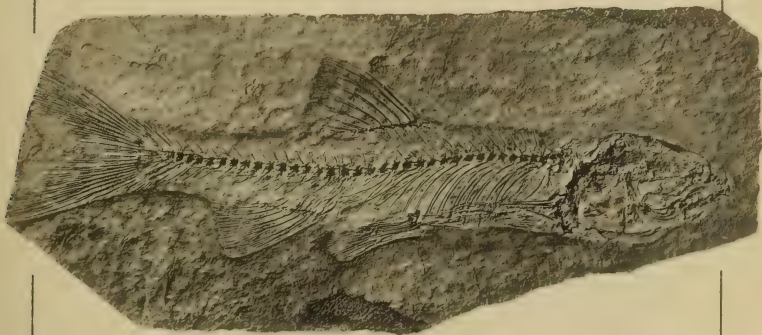
SPECIMENS OF *LEUCISCUS TURNERI* LUCAS, FROM THE ESMERALDA FORMATION.

(All natural size.)

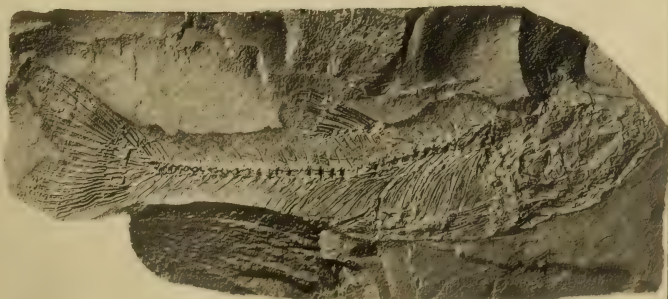
- A. Specimen showing details of pectoral fin.
- B. Type specimen.
- C. Specimen showing details of vertebrae and ribs.



(A)



(B)



(C)

FOSSIL FISH FROM THE ESMERALDA FORMATION
(*LEUCISCUS TURNERI*)

MINERAL VEIN FORMATION AT BOULDER HOT SPRINGS,
MONTANA

BY

WALTER HARVEY WEED

CONTENTS.

	Page.
Introduction	233
Quartz and jasper veins of Boulder region.....	234
Distribution	234
Genesis of the reefs.....	234
Existing hot springs.....	234
Boulder Hot Springs.....	235
Location and general features.....	235
Occurrence of springs.....	236
Character of water.....	237
Hot-spring fissures.....	238
Fissure filling.....	239
Nature of the vein filling	240
Rock decomposition effected by hot waters.....	244
Relation of altered granite to vein fissures.....	245
General character of the altered rock.....	245
Metasomatic alteration of the granite and aplite.....	246
Origin of the vein-forming material.....	248
Gold and silver contents of the veins.....	248
Recent movement or faulting of the veins.....	249
Theory of ore deposition in mineral veins.....	249
Microscopic petrography of the altered rocks and vein filling.....	252
The altered granite	252
Sericite	253
Kaolinite	253
Fibrous silica	253
The jasperoid	253
The filling	254
Structure of filling.....	254

ILLUSTRATIONS.

	Page.
PLATE XXXII. Boulder Hot Springs, Montana	234
XXXIII. Topographic map of Boulder Hot Springs.....	238
XXXIV. <i>A</i> , Specimen showing brecciation of hot-spring deposit by later movement along vein; <i>B</i> , Cellular deposit of silica formed in calcite deposit from which lime carbonate has been extracted by acid, leaving skeleton of silica plates formed along calcite cleavages; <i>C</i> , Specimen showing weathered surface of hot-spring deposit on which the calcite has been dissolved away by weathering and the silica plates left in relief	240
FIG. 6. Index map of Montana, showing location of the Boulder Springs	235
7. Ideal transverse section of hillside, showing occurrence of hot-spring vein	236
8. Netted fracturing of granite alongside of vein exposed in shaft on hill- side, Boulder Hot Springs	238
9. Cross section showing concentric layers of deposit found about upper springs in middle gulch, Boulder Hot Springs	240
10. Crusts formed by hot waters about granite nuclei.....	241
11. Specimen showing fragments of granite incrustated by a hot-spring deposit	241
12. Specimen showing occurrence of crusts formed by a hot-spring deposit, and of the alteration of calcite, with the formation of secondary quartz upon the plates	242
13. The red "jasper" deposit shattered by later movements along the vein and the fragments cemented by newly formed opaline silica and quartz	249

MINERAL VEIN FORMATION AT BOULDER HOT SPRINGS, MONTANA.

By WALTER HARVEY WEED.

INTRODUCTION.

The origin of metalliferous veins by hot waters ascending from great depths has always been a favorite theory with the practical miner, however widely the pendulum of geologic theory may swing away from this side of the arc of thought. Nevertheless, although hot springs are of as world-wide occurrence as ore deposits, examples of ore deposition by hot springs are rare. Indeed, the only examples generally recognized are the familiar ones at Steamboat Springs, Nevada, and Sulphur Bank, California, though the fact that hot waters can dissolve the metals and form ores is established by the observations of Daubrée. In a study of the hot springs of the Yellowstone National Park, begun in 1883 and continued for over seven years, the writer sought diligently for some evidence of ore deposition. It was found that veins of pyrite were forming in fractures in the rhyolite at the Norris Geyser Basin, and that subsurface deposits of realgar and orpiment, and surface deposits of scorodite, as well as calcareous and siliceous sinters, were forming at several localities, but no ore deposits were found forming, nor were any quartz veins found, nor was any evidence discovered to show the genetic connection between hot springs and veins. The writer was therefore much gratified in 1897 to find a hot-spring locality where the waters are still actively at work forming veins, analogous in every way to those which are commonly found in the adjacent mineral districts and which often constitute workable ore deposits. The deposits now forming do not, it is true, carry large amounts of the precious metals, but gold, silver, and copper do occur in appreciable amounts, and it is evident that we have a new locality where mineral deposits—although not of economic value—are now being formed. The locality is also interesting as the only known example in this country of the deposition of zeolites by hot spring waters. A no less important process now in operation is the metaso-

matic replacement of granite by the hot waters, forming the zone of replaced rock which is so common a feature of the quartz veins of the region and in which the workable ores of the veins of the region commonly occur.

QUARTZ AND JASPER VEINS OF BOULDER REGION.

Distribution.—Throughout the granite district of Jefferson County, Montana, a region which extends from Helena on the north beyond Butte on the south and is 15 to 20 miles wide, there are scattered areas where the granite is more or less disintegrated and weathered down to smooth slopes. These areas frequently show reefs or dike-like masses of quartz and jasper which project above the surface and are often traceable for a mile or more. The larger reefs frequently form the crests of ridges and determine the topographic relief of the neighborhood. Often they show a general parallelism, though in other instances they form a network corresponding to three distinct fracture systems. In the Lump Gulch silver district, a few miles south of Helena, the rich silver-lead and ruby-silver ores are found in such veins, and at various other localities in the region the great productive ore deposits occur in them, as, for example, the Comet mine, Gray Eagle, Bonanza Chief, Liverpool, etc. When carefully examined these reefs show a central core or vein of crystalline quartz which varies from a few inches to several feet across. On both sides of this the reef material is generally in part a jasperoid, while the greater part shows a marked granitic texture and is clearly an altered granite in which feldspar and some of the original quartz of the rock has been altered to a white clayey substance. The rock, though highly silicified, shows that it is a metasomatically altered form of the neighboring granite. Very commonly the reef rock is shattered and possesses a marked brecciated structure.

Genesis of the reefs. The origin of these reefs or veins was for a while a puzzle to the writer. They possess none of the characters of hot-spring deposits observed in the Yellowstone; no sinter deposits were found in connection with them, nor do they show any concentric banding or the structural characteristics which characterize the usual material filling hot-spring conduits. In brief, the veins show none of the features commonly characteristic of hot-spring action or deposits.

Existing hot springs.—Existing hot springs are found at a number of places near the borders of the granite mass, notably at Pipestone, Helena, and Alhambra, and at the Boulder Hot Springs. Near Butte hot waters issue from the granite and are probably connected with later rhyolite intrusions. At all these localities except Boulder an examination of the springs threw no light upon the question of the origin of the quartz veins. At Boulder, however, veins are found



BOULDER HOT SPRINGS, MONTANA.

whose connection with the hot springs is undoubted. The hot waters still fill fissures marked by such reefs, and are now forming deposits whose weathered outcrops present all the features of the ore-bearing veins, while assays of the vein filling and of the altered silicified granite alongside of the fissure show the presence of gold and silver in appreciable though small amounts.

BOULDER HOT SPRINGS.

Location and general features.—These hot springs are situated in Jefferson County, Montana, about midway between the cities of Butte and Helena, on the southern side of the Boulder Valley and near the Boulder River. The springs are 3 miles from Boulder, a town on



FIG. 6.—Index map of Montana, showing location of the Boulder Springs.

the line of the Great Northern Railway and on a branch line of the Northern Pacific Railway. The place has been improved by a comfortable hotel and bath houses, and it is a summer resort as well as a place for the treatment of invalids. The slopes of Bull Mountain rise abruptly to the south, and on the north the broad, green meadows of Boulder Valley form a pleasing foreground for a mountain panorama of great beauty (Pl. XXXII).

The hot waters issue from granite at a point a few miles distant from its contact with the older andesitic rocks of Bull Mountain. The rock is a typical coarse-grained granite, consisting of orthoclase feldspar and quartz with lesser amounts of plagioclase feldspar (andesine), brown biotite-mica, and green hornblende. Magnetite, titanite, and apatite are present as accessories.

This granite is sheeted by well-defined joint planes, which, in the vicinity of the spring, have a course of N. 85° E. These joints cause the formation of very rugged slopes, with picturesque groups of monoliths and boulders at various localities near by, and to a less extent close about the springs, but in the hot-spring area itself the granite is weathered down and does not form conspicuous outcrops.

The hot-spring area does not show any of the sinter deposits common about other hot-spring areas. The larger springs near the hotel have no deposits at all. The group a quarter of a mile from the hotel and that 200 feet about it on the mountain slope are marked by low lines of grayish material a few feet wide, showing in some places as a reef or wall a few feet high; and rust-stained jasperoid reefs also occur. The area between these reefs and the hotel is strewn with fragments of siliceous and calcareous material from the upper fissures and from old hot-spring fissures which also traverse this ground. The distribution and course of only the larger veins are shown on the map (Pl. XXXIII)

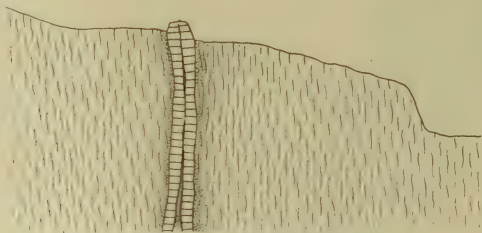


FIG. 7.—Ideal transverse section of hillside, showing occurrence of hot-spring vein.

Occurrence of springs.—The hot springs at Boulder occur in two groups. One of these groups is close to the hotel, the waters flowing from granitic débris a few feet in thickness resting on solid granite. The waters issue from a slight depression or gully a few feet below the general level of the slope. The largest spring has a temperature of 164°, and is the one supplying the bath houses. A measurement of the amount of water flowing from this spring was not possible because it supplies the bath houses and hotel through a system of pipes. A large amount of water flows away and is not utilized. The second group of springs lies at an elevation of about 200 feet above the hotel, the vents being in two small gulches which indent the slope, as shown on the topographic map (Pl. XXXIII). This upper group is much more interesting, though the composition of the water, so far as known, is quite the same as that of the spring near the hotel. These springs are situated on lines which clearly indicate their connection with fissures crossing the granite.

In two cases the hot waters issue from the western end of fissures marked for several hundred feet along the surface by deposits of silica and of calcite. Other springs issue from the southern border of a fissure whose outcrop is also marked by a low and inconspicuous deposit of sinter. The most easterly group is near the log cabin shown on the map (Pl. XXXIII). Here the springs flowing were naturally rather small, and an attempt was made to develop water by artificial means. For this purpose two shafts were sunk to a depth of 10 to 20 feet on the edge of one of the hot-spring reefs and a tunnel was driven into the hillside to tap one of the reefs. Another artificial opening was made on the western end of one of the upper reefs, where it came to the head of one of the gulches, and a pit 5 or 6 feet deep was sunk into the slope. In each instance hot water was obtained, although none whatever showed on the surface, and the fissures were to all appearances dry and the springs dead.

At none of the springs is there any surface deposit of moment now forming. It is true that at one or two of the most active vents a very slight crust is being deposited in connection with the vegetable matter present. If the hot waters are forming any considerable deposit, as would be indicated by the composition of the material found in the tunnel, deposition must be taking place within the fissures themselves and not on the surface. The hot-water streams all contain algae of the usual brown, green, and orange tints in the channels running from the vents. These algae possess the same characteristics as those found in the Yellowstone hot springs, but no specific determination has been made of them. Singularly enough, they are not building up any of the great jelly-like deposits of silica found in the Yellowstone, although it is known that the waters contain considerable silica in solution. The brilliant colorings of these algae, like those of the Yellowstone Park, show a definite relation to the temperature of the water. The red and brown colors are, as usual, ascribed by the ordinary visitor to the presence of iron in the water, but samples of the material when dry lose their color and upon heating are shown to be merely organic material practically free from iron.

Character of water.—The hot spring waters are clear, colorless, and tasteless. The temperature varies from 164° at the big spring near the hotel to 120° in one vent in the hillside group. The outflow from one of the reefs is 152° and that from another 158° . In outflow from the tunnel the water has a temperature of 110° . The waters have a faint odor of H_2S at the spring, but it is not noticeable elsewhere, although the blackening of paint, etc., shows that this is present. The waters do not, so far as could be determined, form any surface deposit of sinter. The conduit pipes used to carry water to the hotel are entirely free from sediment, and in fact are corroded by the waters to a slight extent, as is shown by an iron staining of the porcelain tubs and basins.

The analysis published by the hotel proprietor is as follows, the constituents being stated in grains per wine gallon. The name of the analyst is not given.

Chloride of sodium	4.7
Sulphate of soda	4.3
Carbonate of soda	2.6
Carbonate of lime	1.3
Carbonate of magnesia.....	3.6
Sulphur	4.8
Iron.....	2.9

Hot-spring fissures.—The larger spring, the one nearest the hotel, does not appear to be on a recognizable fissure; the other springs, one-fourth of a mile distant, flow from fissures which may be recognized by the deposit, although the fracture is not open at the surface. These fissures are clearly traceable across the slopes by their definite lines of deposit. Their course varies from nearly east-west in the three parallel and uppermost reefs to northwest in the fissures

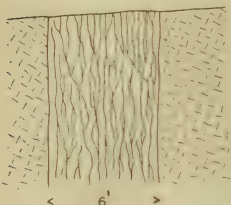
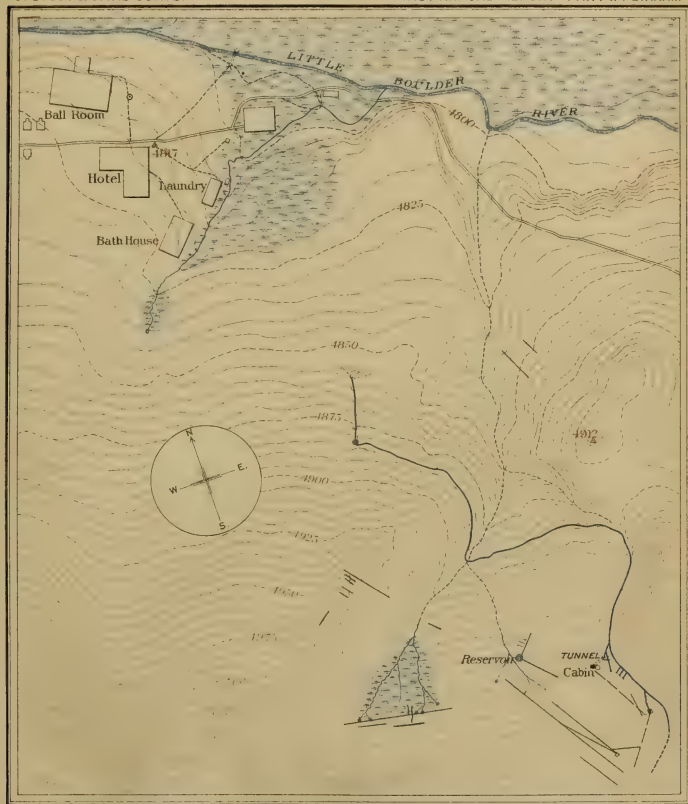


FIG. 8.—Netted fracturing of granite along side of vein exposed in shaft on hillside, Boulder Hot Springs.

ending near the little reservoir. The latter course accords nearly with the pronounced sheeting seen in the granite near by. The courses of the different fissures when compared are found to make angles of 23°, 48°, 60°, 85°, and 108° with one another. Compared with the fissures of the granite where no hydrothermal action has taken place in the immediate vicinity of the springs, there is not entire concordance, the granite showing courses of sheeting of N. 30°,

45°, 49° W., the first two readings being taken near the bath house and the last one near the easternmost fissures. It is at once apparent that, like the jasper reefs observed through the adjacent districts, the course of these hot-spring fissures is not uniform, and that, while certain courses conform to the dominant sheeting of the granite, others correspond to intersecting fracture planes not common in the general granite area. In areas of well-jointed granite the most pronounced sheeting fractures of the granite have vertical walls, while the lesser joints are inclined toward one another at 45°. Where it was possible to make observations upon the outcrops of these hot-spring veins (and in one instance a 20-foot shaft exposed a good section of the vein), it was found that the reefs running N. 70° E. have vertical walls, while those whose course is N. 38° W. dip 70° to the south, and a fissure whose course is N. 22° E. has a dip of 70° to the west. It is therefore evident that they do not conform in dip to compression joints of the granite.



MAP OF BOULDER HOT SPRINGS AREA
BOULDER, JEFFERSON COUNTY, MONTANA

Scale of feet
100 50 0 100 200 300 400 500

Contour interval 5 ft.
Surveyed Aug. 1898 by W. J. Lloyd

JULIUS BIEN & CO. N.Y.

Shafts and a short adit or tunnel, run into the hillside, show that the rock adjacent to the vein fissure is sheeted by rudely parallel and cross-linked fractures. The accompanying diagram, fig. 8, shows the fractures seen in the west wall of one of the shafts. In the wall of the deepest shaft the fractures are 8 to 10 inches apart, but appear to be closer together near the bottom, and all run parallel to the vein walls. So far as observed these link fractures are not the result of intersecting diagonals 45° apart, such as are so common in the rocks. They may result from an irregular fracturing of the rock due to shearing movement.

The plan of the vein or fissure outcrops, like those of the jasper reefs observed at a number of localities about the Boulder Valley, shows an irregular checking of the country rock and seems to indicate torsional strain and not simple shearing. The length of the hot-spring fissures, as indicated by the deposits, is not very great. In no case was such a fissure traceable over a few hundred feet, although a reef has, in one or two instances, been observed on a direct continuation of the line of a fissure beyond its apparent termination.

Fissure filling.—The fissures are known to be hot-spring conduits, because hot water is now flowing from several of them. Most of the fissures are, however, sealed up by the hot-water deposit formed when they were filled to the level of the present surface. This fissure filling forms a vein; it is only by means of this deposit that the fissures may now be traced. The material varies somewhat in outward appearance, as it does in mineral composition. As seen in outcrop it is for the most part of a light-gray color and appears in contrast with both the green marsh of the hollows and the gravelly granitic débris which covers the dry slopes. The deposit does not weather in conspicuous relief, except at the extreme southeast corner of the area mapped, near a log cabin. At this locality there are several reefs or walls. None of them are as large or as persistent as some which may be found in adjacent mineral areas, though quite conspicuous, so that even when the wall is broken down the course of the fissure may be followed by a continuous line of deposit. Above the log cabin there are three parallel fissures, marked by white outcrops and having a course of very nearly N. 70° E. The lower of these three veins is from 5 to 7 feet wide, and in some places is weathered in relief as a wall 3 to 4 feet high. The vein can be traced westward down the slope until lost in a pit cut into the slope, an opening which taps the hot water of the vein and affords a supply utilized by the present owners of the property. At this point the deposit is $2\frac{1}{2}$ feet wide and has a fibrous or thatch-like structure and is shot through with needle-like masses of silica which give it a peculiar felted appearance. The second fissure, which is 24 feet distant and farther up the hill, is but from 10 to 19 inches wide at its east end and stands up a few inches above

the surface. Farther west the vein outcrops as a mass 15 to 24 inches wide and forms a wall about 5 feet long and $2\frac{1}{2}$ feet high. It shows a well-defined vertical north wall, and traverses aplite in part and granite beyond. Still farther west the vein forms a low wall 3 to 6 feet wide, where the light-gray color of the deposit is in strong contrast to the grassy slope. The concretionary structure is very marked in some cases and shows successive crusts formed one upon another, as is seen in the west end of the fissure in the middle gulch (fig. 9).

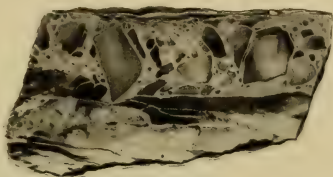
Over much of the area scattered fragments of jasper, chalcedony, and other material that is readily recognized as hot-spring deposit indicate other reefs which have not been located. Moreover, there are several old reefs on the terrace above the Little Boulder River east of the limit of the map, and several veins of hot-spring deposit were recognized on a ridge which runs up from the center of the hot-spring area. As, however, the prominent reefs mentioned and those connected with the existing outflows of hot water show all the characteristics of the others, and there is no doubt as to their origin, no further mention of the extinct hot-spring fissures will be made. The width of the fis-



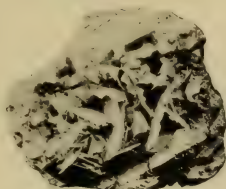
FIG. 9.—Cross section showing concentric layers of deposit found about upper springs in middle gulch, Boulder Hot Springs.

tures, as indicated by well-recognizable hot-spring deposit, the true vein filling, is variable. As stated above, it is from a few inches to several feet in one of the reefs, and in other cases a width of 12 feet has been measured. In general, however, the clearly recognizable deposit does not exceed 2 or 3 feet.

Nature of the vein filling.—As noticed in the Introduction, the deposit found about these hot springs, the origin of which is unquestionably due to the springs themselves, is not of the ordinary type. In some places the reefs do, it is true, show a deposit of calcite having thatch-like structure, like that of the travertines of the Mammoth Hot Spring, but in general the deposit is hard, and consists of a white or dark-gray substance intermixed with more or less red jaspersy material in bands and patches, sometimes carrying included fragments of slightly altered granite, but in large part consisting of a white crystalline substance which is found to be a mixture of chalcedony and stilbite. In external appearance the deposit varies greatly. At the lower of the three veins above the log cabin, already mentioned, the deposit is gnarled and knotty, has a concretionary structure about central points, as illustrated in figs. 10 and 11, and is very dense, though showing a crystalline structure on fresh fractures. In part it appears to be chalcedony and in part it is quartz, but a large portion of this deposit consists of a gray calcite which, when fresh fractured, shows thin films of silica traversing it in a network, but which on weathered surfaces shows a honeycombed or cellular structure much like that



(A)



(B)



(C)

DEPOSITS FROM VEIN FISSURES, BOULDER HOT SPRINGS, MONTANA

of the quartz of certain mineral veins (Pl. XXXIV), notably of the De Lamar of Idaho, the Elkhorn of Montana, and the Drum Lummon of Marysville. The weathered deposit also shows at times a mossy

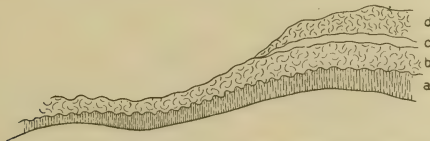


FIG. 10.—Crusts formed by hot waters about granite nuclei. *a*, Stilbite and silica; *b*, curly textured opaline silica; *c*, opaline silica; *d*, calcite.

surface, with distinct crusts and bands of silica, and also fragments of a chert-like substance projecting in relief above the general surface of the rock. Opaline silica also appears irregularly distributed in



FIG. 11.—Specimen showing fragments of granite encrusted by a hot-spring deposit. The deposit consists of layers of silica and of stilbite mixed with silica. The layers are well marked, and some of them are tinted by small amounts of iron oxide, so that a distinct concretionary structure is apparent. The cross-hatched areas are calcite. Drawn from nature; one-half natural size.

bunches through the mass, as well as in bands and curly layers. On fresh fracture it is usually dark gray and very hard. The upper reef shows included fragments of granite, the fragments ranging from

several inches across up to one which was 10 inches wide and 3 feet long. In these fragments the granite is but slightly altered, showing the hornblende changed to chlorite or a green earthy substance. The biotite is clearly recognizable, though partly altered and bronzy in color, while the feldspar shows alteration along cracks and seams. The specimen illustrated in fig. 11 was taken from this vein, and shows quite clearly the normal breccia structure of a mineral vein.

One of the reefs lying to the southeast of the log cabin and parallel to the gully which runs down the slope at this place is a typical silica or jasperoid reef. It consists of a breccia, or more or less altered fragments of granite cemented by a dark-brown jasper, which in the weathered outcrop appears to be largely brown and red iron oxide. The reef wall dips at 65° to 70°. A cross section shows a band a foot wide of solid jasper with irregular colored banding, shading on the east side into a brecciated material. This breccia clearly shows the replacement of granite fragments, but there is undoubtedly also a shattering of the original deposit. This reef can be traced for about 75 feet up the slope from the shaft in its lower end.

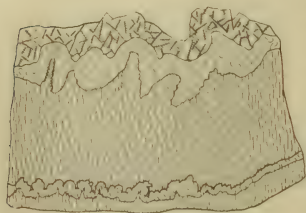


FIG. 12.—Specimen showing crusts formed by a hot spring deposit, and the alteration of calcite, with the formation of secondary quartz upon the plates.

At one place, where it has been opened by blasting, it shows a seam 90° to its course, and here is seen to consist of altered granite like that which will be mentioned later in discussing the alteration of the granite adjacent to the veins. The cross fractures here are filled with secondary silica. The ledge appears to wedge out southward and not to run into splits and stringers, though films of chalcedonic silica were observed running off from the end into the apparently unaltered granite.

The jasper-like deposit is brick red to dark red in color, but when examined under the microscope is found to consist of a very fine paste of altered rock fragments, together with more or less cryptocrystalline silica. The siliceous bands seen are in part true chalcedony and in part opaline amorphous silica. Quartz veinlets also occur in the red jaspery material, and abundant quartz of the typical vein-quartz type was seen scattered over the surface, though none was actually found in the hot-spring deposit itself.

A large part of the hot-spring deposit consists of calcite which is netted with silica films. As already noted, the structure of this material is peculiar. The weathered surface is shown on Pl. XXXIV. C,

and in detail in the diagram, fig. 12. When the fresh material is treated with dilute hydrochloric acid the calcite is entirely removed, leaving a cellular material consisting of almost pure silica, the structure corresponding very nearly to that of the weathered outcrop and to that of the vein quartz noted at various localities, as shown in Pl. XXXIV, *B*. In this material, of course, the films of silica are extremely thin, rarely exceeding the thickness of a sheet of paper, and are very fragile. There is none of the crystalline coating or drusy surface observed in the weathered material, or in the De Lamar quartz. An analysis of the substance gave—

	Per cent.
CaCO ₃	81.16
MnO ₂.....	.34
Insoluble in HCl.....	18.50
	<hr/> 100.00

An analysis of the insoluble material yielded—

	Per cent.
SiO ₂	87.7
Al ₂ O ₃	8.4
CaO.....	3.9
	<hr/> 100.0

The zeolite material is mostly pure white or cream-white, but is sometimes stained pink or red by ferric oxide. It has a distinctly crystalline or granular structure and in hand specimens often resembles the aplites of the region. It seems to form the greater part of much of the deposit, but is intimately mixed with silica. A determination of this material, made in the chemical laboratory of the Survey, shows the following composition:

	Per cent.
Silica.....	87.2
Al ₂ O ₃	4.0
CaO.....	1.5
K ₂ O.....	0.3
Na ₂ O.....	0.7
Insol. not SiO ₂	1.2
Loss on ignition.....	4.9
	<hr/> 99.8

Silica soluble in Na₂CO₃ after treatment with HCl 6.3 per cent.

Disregarding the admixture of silica, the analysis shows the silica, alumina, lime, soda, and moisture to be present in the following proportions:

	Per cent.
SiO ₂	6.3
Al ₂ O ₃	4.0
CaO.....	1.5
Na ₂ O.....	0.7
H ₂ O.....	4.9

The zeolite is therefore stilbite, and the deposit consists of this mineral mixed with chalcedonic silica.

About the veins where the hot water is now flowing little if any deposit is actually forming, though the waters issuing from the fissure ending at the reservoir seem to be adding to the fissure deposit at that place. The nature of the material carried in solution by the waters can, however, be judged by the deposit now forming in the walls of the tunnel driven into the hillside near the log cabin. This deposit forms as an efflorescence without crystalline structure, having a moss-like or mammillary appearance, coating the warm and altered granite walls. It is almost pure white, though stained in some places by fragments of altered granite and more rarely by brilliant red iron oxide. An analysis was made in the Survey laboratory, with the following results:

	Per cent.
Soluble in water	88.27
Soluble in hydrochloric acid (equals CaCO_3)	5.72
Insoluble in HCl (equals SiO_2 , etc.) ¹	6.01
	<hr/> 100.00

The composition of the material soluble in water is as follows:

	Per cent.
Na_2SO_4	47.25
Na_2CO_3	28.33
NaCl	1.09
CO_2	1.96
SiO_2 .....	.25
Difference, mainly H_2O	9.39
	<hr/> 88.27

The CO_2 is in excess of that making normal carbonate.

This deposit clearly shows that the waters are leaching out soda from the granite, and accords with the microscopic examination of these rocks as described later. The substance whose analysis has just been given was tasted in the field, as it was suspected that it was a carbonate or sulphide, but it was apparently tasteless. It is believed that this is because the silica occurs as thin films or concentric shells formed by evaporation upon the surface of the deposit.

Rock decomposition effected by hot waters.—The granite adjacent to the hot-spring fissures is much altered by the hot waters. This is well shown by the exposures formed in the three shafts sunk alongside the veins and by the open cut made in one end of a vein, and also by the pits sunk in the altered granite at the head of the western hot-spring gully. In general, however, this hot-spring locality is lacking in those areas of broad and profound fumarolic or solfataric alteration where steam or acid vapors are ascending, usually found in such districts, and so common throughout the Yellow-

¹90 per cent silica.

stone Park. It should be stated, however, that the surface wash of the disintegrated granite partly covers the slope and hides all evidence of rock alteration.

Relation of altered granite to vein fissures.—The exposures seen in shafts, tunnel, and open cut show that rock alteration has taken place along the fractures which net the rock. The conditions seen in the tunnel and in the shaft 200 feet or so from the cabin show that the granite is more or less generally permeable, as if it were disintegrated to a coherent but loose-textured mass. In most cases the reddening of the rock is confined to the seams which traverse it and occurs in bands one-quarter inch to 2 inches in width, the transition to the less altered nuclear boulder being gradual. These red seams commonly hold a central film of iron oxide or silica, and sometimes a jasper-like substance. In the tunnel the rock is more generally altered. It shows parallel and linked fractures marked by films of silica .01 mm. wide. The different rhombs between fractures vary one from another in color, and are sometimes mottled. The tints are reds, orange, yellow, and the various tones due to iron oxides. The rock is coherent, but crumbly under pressure, and quite thoroughly disintegrated throughout the entire length of the tunnel. It is saturated with warm water, which is of course most abundant near the face of the adit.

In some instances the granite, though altered, is still gray, and the fractures are defined by flows of pale-yellow chalcedonic silica.

General character of the altered rock.—The altered granite is abundant in the dump heaps of the shafts. It is commonly of a red-purple or sometimes a yellow tint, or is mottled with these colors. Its most marked feature is a stippling of the rock with white spots, which often show a rectangular outline. These spots give the rock a decided porphyritic appearance. They are creamy white on surfaces exposed to the weather, but on fresh fracture are seen to be due to pale-greenish irregular masses with the greasy luster of sericite. Aplite, too, is much altered, having usually a very pale greenish or pink color and showing to the eye abundant sericite. These altered rocks, if compared with the fresh granite of the region, show a similar structure, but there is a marked absence of hornblende, augite, and biotite. The feldspars are replaced by the pale greenish-yellow sericite masses and the quartz is shattered and in part eaten into and replaced by sericite. All gradations to fresh granite may be seen, in which the mode of attack of the feldspar and quartz is apparent. About fractures there is a local concentration of the iron. In the most brilliantly colored specimens of the altered granite the rock shows only white kaolin, some glassy quartz, and a red groundmass. The kaolin corresponds to the sericite, and the red band is largely shattered quartz with the fractures filled by iron oxide.

Examinations of thin sections of the rocks in various stages of alteration show that metasomatic replacement is actively going on. That it is due to the hot spring waters seeping into the shattered wall rock of the veins there can be no doubt. The evidence of the slides shows that the granite is being sericitized. Not only are the hornblende, biotite, plagioclase, and orthoclase attacked in the general order given, but the quartz is abundantly attacked and is being altered to sericite—a phenomenon discussed by Lindgren for the altered rocks of ore deposits, but never, so far as known to the writer, described as a result of actual hot-spring action. The hot spring waters are actually altering the granite and removing its soluble constituents. In the lack of a good analysis of the water we can judge its contents by the deposit now forming on the walls of the tunnel. This consists chiefly of sodium sulphate, together with sodium carbonate (in part bicarbonate), a very little sodium chloride, and calcic carbonate and silica. The waters are therefore plainly alkaline, and, as shown by comparison of the fresh and decomposed granite, are leaching the rock, carrying part of its substance off and concentrating the insoluble material in the open spaces. While, therefore, the deposits are in large part the filling of open fissures and show crustification and banding, and at times contain coated fragments of country rock, there is also extensive metasomatic replacement, or the formation of deposits due to such action.

Slides of both the vein filling and the altered granite have been submitted to Mr. Lindgren for examination, as he has probably studied the decomposed rocks about mineral deposits more than any other geologist in this country. He finds that the vein filling consists partly of quartz of medium coarse grain, with which are intergrown prisms and imperfect crystals of stilbite. The double refraction of the latter mineral is weak. Adular feldspar also occurs in a little veinlet.

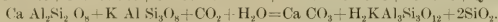
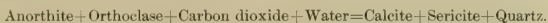
Metasomatic alteration of the granite and aplite.—The granite adjoining the vein is considerably altered, the alteration consisting in the development of two minerals, sericite and kaolinite. Either of the two may locally predominate, and both the feldspar and the quartz are being attacked and replaced by these minerals. There are no remaining ferromagnesian minerals, their place being taken by kaolinite and sericite. Tufts and needles of rutile are mixed with this mass. The alteration usually begins between the grains and gradually eats into them. Long tufts of radial sericite may develop in the interior of orthoclase crystals. A grain of pyrite and some copper stain were noted in the altered granite. There is practically no calcite in the altered rock, and it seems that the calcic carbonates resulting from the soda-lime feldspars must have been carried out into the fissure and there deposited.

To the eye the sericite is apparent on exposed masses as white clayey-looking spots, which give the rock a porphyritic appearance. On freshly fractured surfaces these spots are of a pale-green tint. Under the microscope thin sections show that all the minerals of the granite, including quartz, are attacked. The dark-colored minerals have entirely disappeared, the smaller anhedral orthoclase and the plagioclase are nearly gone, and the large orthoclase masses and quartz are eaten into and show tufts and masses of sericite in cleavage cracks and in apparently isolated patches in the center.

Sericite, as the minutely fibrous or tufted variety of muscovite is called, is the most common of all the minerals resulting from the alteration of rocks by vein waters. Critical examination of the so-called clays and talc and of much of the "kaolin" of most mineral veins shows that they consist largely of sericite, which is nearly insoluble and forms from all the common rock-making minerals, though it is most readily formed from feldspar. It may be formed by waters holding CO_2 simply, but more commonly alkaline carbonates as well. In the first stages of attack it is seen as a clouding of the mineral, and as tufts and scales along cleavage planes, or as strains in cracks, but finally it invades the whole crystal and reduces it to a felted mass of sericite fibres. For orthoclase, Rosenbusch gives¹ the following equations as representing the change:



Sericite is readily formed also from plagioclase, the potassic carbonate formed by the foregoing reaction replacing lime, and the latter substance forming calcite in situ or being carried off by the hot spring waters as bicarbonate, to be deposited, as it is at Boulder, as vein filling. This reaction is as follows:



The hornblende and augite of the granite probably alter first to chlorite and this to sericite and pyrite, or in the presence of oxygen to limonite. The biotite alters easily, losing iron and magnesia and forming sericite and rutile.

That quartz also alters to sericite is now well known. The thin sections of the Boulder rock show it developing abundantly along strain cracks and also in cavities corroded into the surface of the mass. Just what chemical reactions are involved is not certain. The quartz is soluble in waters containing alkaline carbonates, but the sericite is not. At the same time both potash and alumina occur in many natural hot waters of alkaline reaction, and the silica dissolved by the waters may at once unite with potash and alumina and form sericite.

¹ Elemente der Gesteinslehre, Stuttgart, 1890, pp. 70, 71.

ORIGIN OF THE VEIN-FORMING MATERIAL.

It is evident from the foregoing reactions that the waters may derive their alkaline carbonate and silica from the leaching of the vein walls. If the hot spring waters contain CO_2 they will alter orthoclase and plagioclase, the resulting product being sericite, silica, and carbonate of lime, while sodic carbonate derived from both the soda-bearing orthoclase and the plagioclase (andesine) will be carried in solution.

The altered rocks are all oxidized and show much red and yellow oxides of iron and of sericite. Iron pyrite was not found except in one thin section. This lack of pyrite is believed to be due to oxidation taking place near the surface, which acts upon the sulphureted hydrogen of the hot-spring waters, and changes the pyrite to iron sulphate. The resulting materials would at once be neutralized by the alkaline carbonates of the waters, resulting in the bright-colored oxides of iron seen. Patches of hematite were also found in the red jasper, and as the distribution of the iron oxides through the hot-spring deposit indicates that it has been derived from pyrite, it seems evident that the change has taken place since the sealing up of the fissures and the retreat of the waters to a lower level. This would explain also why so little sulphureted hydrogen occurs in the outflowing waters. In common with the pyrite formed by it in depth, and which it is believed exists in abundance in the altered wall rocks of the veins below, it has formed sulphuric acid by oxidation, and this has been neutralized by the carbonates of the waters, with the production of sodium sulphate and sesquioxide of iron. The overflow at the upper springs is not energetic enough to bring the waters to the surface with their normal deep-seated character. At the lower spring, near the hotel, the phenomena of rock alteration or mineral deposition can not be studied to advantage, owing to the boggy character of the ground about the spring.

GOLD AND SILVER CONTENTS OF THE VEINS.

The mineral contents of the veins are insignificant from an economic point of view, though of much scientific interest, as they prove that the fissure filling constitutes true mineral veins. Assays made by C. E. Monroe for the Survey show the following results:

	Oz. per ton.
White calcareous vein filling.	{Gold..... 0.05
	{Silver..... .40
Altered granite alongside vein.....	{Gold..... Trace
	{Silver..... 0.40
"Jasperoid" vein filling	{Gold..... Trace
	{Silver..... 0.05

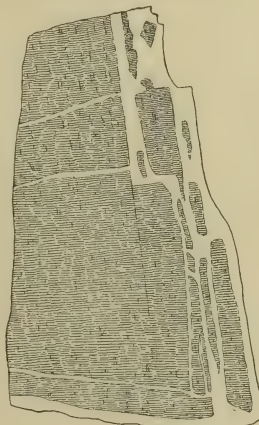
Copper stains are prominent in flat fractures of the altered granite exposed in the shafts, and specimens of the red "jasperoid" show

patches of crystalline specular hematite. Pyrite is seen in thin section, and the red hematite staining is in part derived from pyrite and not from altered ferromagnesian minerals.

The solubility of gold in waters holding sodic carbonate and sulphureted hydrogen was established by Becker in his study of the quicksilver deposits of the Pacific slope.¹ As stated by him, these substances are common constituents of hot-spring waters, and they occur in the waters of the Boulder springs. The origin of the gold is believed to be the granite itself. The occurrence of the large ore deposits of the State in veins cutting the basic peripheral masses of granite batholiths is significant, however, as indicating that the veins have derived their precious-metal contents from the leaching of the basic border rocks.

RECENT MOVEMENT OR FAULTING OF THE VEIN.

The brecciated character of part of the hot-spring deposit shows that this vein filling has been broken by movement or faulting since its formation, and there is no reason to doubt that such movements are still in progress, and that crustal adjustment is still going on. Some emphasis is laid upon this fact, as it shows that a fissure may be completely filled, forming a vein, and that this vein may reopen and become brecciated by later movement. The specimens figured (Pl. XXXIV, A, and fig. 13) show the brecciation of the red jasperoid and its recementation by silica.



THEORY OF ORE DEPOSITION IN MINERAL VEINS.

The origin of the heat of the Boulder hot springs is believed to be deep seated; it is probably connected with the rhyolite intrusions which formed the latest manifestation of volcanic activity in the region. These rhyolite rocks occur in dikes and irregular intruded masses rather commonly throughout the entire granite region. They also form large areas of extrusive rocks covering the granite. Although no rhyolite was found near the springs, the widespread occurrence of such intrusions indicates a general source of supply—a reservoir of heated rock which may have supplied the heat of the present hot springs. The fact that fissures are still forming in this region

FIG. 13.—Diagram showing the red "jasper" deposit shattered by later movements along the vein and the fragments cemented by newly formed opaline silica and quartz. Drawn from nature. Shaded part is red jasper; white is chalcidony.

¹ Geology of the quicksilver deposits of the Pacific slope, by George F. Becker: Mon. U. S. Geol. Survey, Vol. XIII, 1888.

shows that meteoric waters could penetrate to a depth sufficient to become heated and rise again along trunk channels, such as those of the hot springs themselves. In other words, the springs owe their heat to the lingering traces of volcanic action of which the rhyolites are the main evidence. This theory, too, accords with the widespread occurrence of the jasper reefs, which indicates the former existence of hot springs over the region.

It has long been believed by a majority of the students of ore deposits, and by most mining men, that such deposits are formed by hot waters ascending from unknown depths. For a decade or two the advocates of the theory of ore deposition by descending waters or laterally moving currents obtained a qualified acceptance of their hypothesis, but in recent years there has been a reaction, a return to the ascension theory. One good result, however, of the discussion following the presentation of the theory of lateral secretion has been a general recognition of the fact that ore deposits are formed in many different ways. During recent years researches have demonstrated that openings can not exist in the rocks which compose the outer crust of the earth at depths of 30,000 feet or more, and that, indeed, under certain conditions, they can not exist at depths very much less than that. Observations made upon deeply buried rocks brought to the surface by uplift and erosion are in perfect accord with these deductions, and prove that the "unknown depths" from which ore deposits in waters are derived can not exceed these figures. In a geological study of the hot springs in the Yellowstone National Park and in adjacent parts of Montana the writer long ago became convinced that the source of the heat is not truly profound,¹ but that the springs are of meteoric origin and form part of the normal underground circulating water of the region, heated by physical conditions giving it access to the still hot rocks beneath. It is not necessary, therefore, that the ascending hot waters which are commonly supposed to deposit ores should come from very great depths.

Assuming this to be true, it will probably be admitted, since heat and pressure facilitate solution, that hot waters circulating at considerable depths will dissolve and take into solution various materials, metallic and otherwise, with which they come into contact. The capacity of the hot water to contain such substances in solution will depend upon heat and pressure. The water will take up the less readily soluble salts only while the conditions are favorable. With less heat and pressure the solution may become saturated for any one substance and, though still holding it in solution, be incapable of taking up any more of that substance. In this unstable condition a slightly lessened temperature and heat would bring about precipitation.

In an ideal hot spring meteoric waters, slowly traversing heated but solid igneous rocks, out of which they dissolve various substances,

¹ Smithsonian report 1893, pp. 163-178; *School of Mines quarterly*, New York, Vol. XI, pp. 289-306.

flow toward the point of easiest escape, which is the hot spring fissure. For convenience we will assume this fissure to be straight, a thousand or two thousand feet deep, and the waters to move upward very slowly. In its lower part, as in the pores of the adjacent rocks, heat and pressure are very great and the waters are not saturated, even for the most insoluble substances, and no minerals are deposited. Nearer the surface diminished heat and pressure make the water incapable of taking more of the less soluble materials in solution, forming what may be conveniently called the zone of saturation. Some salts, like alkaline sulphates, etc., are extremely soluble, and the point of saturation is scarcely ever reached in nature, even at the earth's surface. Others, like silica, may be present in such amount as to saturate the water, but the solution is clear until cooling and relief of pressure cause supersaturation and precipitation occurs; a case seen at the Opal and the Coral Springs of the Norris Geyser Basin, in the Yellowstone Park. Still higher in the hypothetical hot-spring pipe diminished heat and pressure cause the separation out of the less soluble constituents, and for such materials this part of the tube is the zone of precipitation. It is well known that the metallic sulphides are soluble in alkaline solutions under heat and pressure, but examples showing their deposition by living hot springs are extremely rare. The more soluble substances will be carried farther upward before precipitation, and one might even suppose, if the solubilities of the substances were sufficiently unlike, that zones would be formed each one consisting mainly of the particular substance thrown out by the change of pressure. This would produce an orderly distribution of the ores in a vertical direction. This, indeed, has been frequently observed. Chamberlin records it for the lead and zinc deposits of Wisconsin, and Rickard¹ for those of Colorado and elsewhere. In the writer's own experience the order appears to be galena on top, passing into highly zinciferous ores below, and this into low-grade pyrite. It is a common experience to find this association in silver-lead deposits in limestone. This would account also for impoverishment in depth and the passing into the ever-present and readily deposited silica.

The conditions in a hot spring tube are admittedly those postulated, i. e., lessening heat and pressure as the surface is approached, and the assumptions made are natural ones. This, then, would explain why hot springs do not deposit metallic sulphides at the earth's surface. Owing to their relative insolubility these are deposited (if present in the water) at depths below the surface. The Sulphur Bank quicksilver mines of California are examples. At the surface they showed only sulphur and no quicksilver. In depth quicksilver ores appeared. Were these springs to die out and degradation to remove the upper 200 feet of the ground, quicksilver veins would be exposed. It is probable that somewhat analogous conditions may exist at many

¹ F. A. Rickard, *Trans. Inst. Min. and Metal.*, London, Vol. VI, 1899, p. 196.

hot-spring localities and that if we could expose the lower part of the conduit we should find ore deposits. This is the theory which the writer at present holds as to the genesis of the silver-gold veins of Lump Gulch and other mining districts of Jefferson County, Montana, and which he believes is a rational ascension theory. All secondary alterations are here excluded, these remarks applying only to the primary vein filling. It is lateral secretion only in the very special and limited application of that term to the leaching of relatively deep-seated rocks and the gathering of such waters in a hot-spring conduit.

The close resemblance in nature and occurrence of these Boulder hot-spring veins to the jasper reefs of Clancy, Lump Gulch, and many other mining districts in the granite area of Jefferson County has already been stated. It may be accepted as certain that they also owe their origin to hot springs and that the ore deposits of such veins were formed by hot waters.

MICROSCOPIC PETROGRAPHY OF THE ALTERED ROCKS AND VEIN FILLING.

Mr. Waldemar Lindgren has kindly furnished the following notes upon the petrographic characters shown in thin sections of the rocks from this locality.

THE ALTERED GRANITE.

The fresh granite of Boulder, Montana, is related, as shown by Mr. Weed, to quartz-monzonite. The rock consists of a medium-grained aggregate of quartz, orthoclase, plagioclase (predominantly andesine), brown biotite, and a little titanite. As secondary minerals a small amount of chlorite connected with biotite appears, while sericite and muscovite are absent. Adjoining the vein this granite is altered to a reddish, crumbly rock, in which the biotite has disappeared and the feldspar is partly replaced by a soft, grayish mass. Large quartz grains remain in the rock, which is porous by many large spaces of dissolution.

Aplite is also seen in thin sections and these show a scarcity of biotite, an absence of andesine, and a structure which appears more like a mosaic than the original idiomorphic structure of the quartz-monzonite.

A considerable amount of orthoclase and quartz remains unaltered, even in the specimens most attacked by the metasomatic processes. The altered rock contains abundant spots and nests of fine-grained secondary aggregates, which appear between the grains and gradually corrode the adjoining primary constituents. Many of these secondary aggregates appear in the middle of some grains of quartz and feldspar, and are gradually spreading outside. Near the secondary aggregates the quartz and feldspar are generally completely filled with irregular fluid inclusions, generally massed on planes of fracture, but in these

inclusions no secondary minerals have separated out. Some aggregates in the rock appear, to judge from their structure, to replace biotite. Besides the later-described minerals they contain bunches of rutile needles.

The secondary aggregates consist of:

Sericite.—This mineral develops in places in unusually large foils, replacing orthoclase and, to some extent also, quartz; they are associated with the minerals described below. The larger part of the sericite appears, however, as bent, irregular fibers, which sometimes develop directly in the feldspars, or, again, are mixed with other secondary aggregates.

Kaolinite.—This mineral is in some sections present in much larger quantities than the sericite, although in all of these rocks the two minerals occur together. The kaolinite forms an aggregate of minute scales of irregular outline, which presents very low colors of interference and occasionally fibrous structure, as shown by the action on polarized light. The mineral occurs in large aggregates and can easily be distinguished from the sericite often embedded in it. Much more difficult is the distinction from the secondary quartz described below, and the study requires strong magnifying power. Kaolinite replaces the feldspar, orthoclase, or soda-lime feldspar, but it also distinctly forms from the quartz, and many grains of the latter may be seen in process of kaolinization.

Fibrous silica.—Intimately mixed with the kaolinite are very irregular grains and shreds of secondary quartz having a pronouncedly irregular fibrous structure. The mineral has a little higher double refraction, but somewhat lower refraction than the kaolinite. It is doubtless a peculiarly developed variety of chalcedony.

Some fragments of aplite which are inclosed in a quartzose ground-mass, probably a consolidated and altered mud, present phenomena of replacement a little different from those described, inasmuch as the secondary silica predominates and the final product appears to tend toward a fine-grained jasperoid. The quartzose grains in these included fragments are not much altered, though considerably shattered. The orthoclase is opaque by minute inclusions and is also traversed by a network of veins of predominating secondary quartz, with some kaolinite and a very little sericite. The silica appears as minute quartz grains, not as chalcedony. This is not really a shattering and recementing, but a process of corrosion involving replacement certainly takes place, by means of which the feldspar is silicified.

THE JASPEROID.

Many of the specimens consist of a reddish, very fine-grained chert or jasperoid, which is traversed by minute veinlets of quartz and stilbite and which contains many small fragments of apparently clastic quartz grains. Under the microscope these grains are seen to be clearly

elastic and apparently not corroded or replaced. The principal mass is exceedingly fine grained and contains many small inclusions of red oxide of iron as well as scattered aggregates of light-greenish serpentinite material. There are also a few small aggregates which unquestionably consist of kaolinite. The prevailing mass appears between crossed nicols as a feebly double-refracting material with extinctions over large areas as a sort of shadowy network. The character of this mineral is in some doubt. It appears that the specimen is largely composed of quartz or allied mineral, and the substance described may be a peculiar form of fibrous silica. Altogether it is probable that this fine-grained chert is not a product of replacement, but a filling, or perhaps a partial replacement of finely comminuted material mixed with some coarser grains.

The little veinlets traversing the rock consist of a very fine-grained mosaic of quartz. Along the walls small groups of stilbite crystals have grown, presumably prior to the later filling.

THE FILLING.

The filling consists of quartz, stilbite, and calcite. As shown in many specimens, the following is the order of deposition: Next the wall 5 mm. of granular stilbite are covered by 4 mm. of quartz crust. This, again, is covered by 25 mm. of mixed zeolites and quartz, with a little calcite toward the interior. The central part appears to consist of some centimeters of cellular pseudomorphic quartz, accompanied by some calcite. On this framework of silica little warts of opal or hyalite are sometimes deposited. From all specimens it is apparent that subsequently to the deposition of the main mass of stilbite granular calcite was formed, which again has been dissolved and partly replaced by zeolites and quartz.

Structure of filling. The main mass, consisting of zeolite and quartz, appears in thin section as a network of prismatic crystals cemented by a mosaic of quartz grains. The prismatic crystals have very low refracting and birefracting power. The cleavage in one direction is excellently developed, with pearly luster on the face. The extinctions from the vertical axis range from 0° to a maximum of 15°. In the sections of the zone perpendicular to the base cleavage the extinction is 0°. The character of the double refraction is negative. From all these data the conclusion that the zeolite is stilbite may be drawn with considerable confidence. One prism was found having an extinction of 34°, and another, also monoclinic or triclinic, in which the double refraction was of positive character. It is thus possible that a few grains of different minerals, also zeolites, may be admixed with the main mass of stilbite.

The coarsely granular calcite forming the later part of the filling is characterized by a prevalence of spear-shaped grains and long, slender

prisms. The triangular interstices are sometimes filled with granular quartz. One section shows well the beginning of the alteration of this calcite to secondary quartz and stilbite. Along the contact lines of the long, slender, calcite prisms pseudomorphic action begins by deposition of a narrow rim of quartz mosaic. From this medium line long, slender crystals of stilbite project on both sides into the fresh calcite. Some crystals of the same mineral also develop in the calcite itself. By the gradual growth of this secondary mineral simultaneously with the dissolving of the calcite the primary aggregate of this mineral is converted into a cellular, honeycombed mass of quartz and stilbite.

GEOLOGY OF THE EASTERN CHOCTAW COAL FIELD
INDIAN TERRITORY

BY

JOSEPH A. TAFF AND GEORGE L. ADAMS

CONTENTS.

	Page.
Introduction	263
Boundaries of the field	263
Previous publications	263
Maps	264
Acknowledgments	265
Topography	265
General relations	265
Ouachita Mountains region	266
Arkansas Valley region	267
Lowland plain	267
Highland plain	268
Ridges of the highland plain	268
Mountains	270
Stratigraphy	271
General relations	271
Character of sediments	272
Atoka formation	273
Hartshorne sandstone	274
McAlester shale	275
Savanna formation	276
Boggy shale	278
Structure	279
General relations	279
Folds	279
Kiowa syncline	279
Poteau syncline	280
McAlester anticline	280
Heavener anticline	281
Sugarloaf syncline	282
Cavanal syncline	282
Brazil anticline	282
Sansbois syncline	283
Milton anticline	283
Backbone anticline	283
Bokoshe syncline	284
Faults	284
Choctaw fault	284
Backbone fault	285
Distribution of coal	285
Hartshorne coals	287
In the Hartshorne Basin	287
In the Sansbois syncline	287
In the Cavanal syncline	289

Distribution of coal—Continued.	
Hartshorne coals—Continued.	Page.
In the Heavener anticline.....	289
In the Poteau syncline.....	290
McAlester coal.....	291
In the Sansbois syncline.....	291
In the Brazil anticline.....	291
In the Cavanal syncline.....	291
In the Poteau syncline.....	292
Cavanal coal.....	292
In the Cavanal syncline.....	292
In the Sansbois syncline.....	293
Witteville coals.....	294
In the Cavanal syncline.....	294
In the Sansbois syncline.....	295
In the Poteau and Sugarloaf synclines.....	295
Other coals in the eastern Choctaw coal field.....	295
Mining development.....	296
Mining districts.....	297
Cowen district.....	297
Willburton district.....	297
Ola district.....	298
Panola district.....	298
Red Oak district.....	298
Turkey Creek district.....	298
Fanshawe district.....	299
Pocahontas district.....	299
Wister district.....	299
Howe district.....	300
Mitchell Basin district.....	300
Cavanal district.....	300
Poteau district.....	300
Witteville district.....	301
Mayberry district.....	301
Jenson district.....	301
Panama district.....	302
Pocola district.....	302
Tabular summary of mining operations.....	304
Composition and adaptability of coals.....	305
Analyses of coals.....	307
Methods of sampling.....	310
Classification of coals.....	310
Variation of coals.....	311

ILLUSTRATIONS.

	Page.
PLATE XXXV. Map of the Choctaw Nation, showing the southern limit of the coal field and the area surveyed.....	264
XXXVI. Map of the Choctaw coal field, showing axes of the folds and crops of the principal coal beds.....	280
XXXVII. Map of the Eastern Choctaw coal field, with five structure sections	In pocket.
FIG. 14. Vertical section of coal and associated rocks in the Hartshorne Basin, at the west end of Long Mountain	287
15. Section across the Hartshorne Basin through Long Mountain.....	288
16. Section through the mines at the west side of Wilburton.....	289
17. Section of rocks at the Potter mine.....	290
18. Section of coals and associated rocks in the Mitchell Basin.....	291
19. Section of coal in the Cavanal mine	292
20. Section of the Witteville coals and associated rocks at the Witteville mines.....	295

GEOLOGY OF THE EASTERN CHOCTAW COAL FIELD, INDIAN TERRITORY.

By JOSEPH A. TAFF and GEORGE I. ADAMS.

INTRODUCTION.

Boundaries of the field.—The Eastern Choctaw coal field is the direct eastward continuation of the McAlester-Lehigh or Western Choctaw coal field, which was mapped and reported upon in the Nineteenth Annual Report of this Survey. It extends to the Arkansas-Indian Territory line, whence the same coal-bearing rocks continue down the Arkansas River Valley about 75 miles, to the eastern termination of the Arkansas coal field. The outcrop of the Hartshorne sandstone, as shown on the map, is the southern boundary of the Eastern Choctaw coal field. A short distance south of the outcrop of the Hartshorne sandstone a fault bearing nearly east and west separates the coal-bearing rocks on the north from the rocks on the south, in which no coal has been found in Indian Territory. The plane of this fault dips steeply away from the coal field, and the rocks south of it have ridden upward and over the rocks on the north side. The movement or displacement along this fault is estimated to be several thousand feet, so that the rocks on the south side now on a level and in contact with those on the north are the older. During the time of faulting or since it occurred the rocks on both sides of the fault have been reduced by erosion to the same plane. The northern limit of the field mapped and discussed in the following pages is not the natural limit of the productive or workable coals, but is arbitrarily drawn at the northern boundary of the area surveyed up to the present time.

This part of the coal field, comprising an area of nearly 750 square miles, is the extreme southeastern part of the Coal Measures of Indian Territory, which have an area of nearly 20,000 square miles. The Indian Territory coal field connects that of Arkansas with the fields of Kansas, Missouri, and Iowa.

Previous publications.—In 1890 Dr. H. M. Chance made a survey of the southern border of the Choctaw coal field from the region of Harts-

horne to the Arkansas State line.¹ His paper is the first publication of any consequence concerning the geology of this region. With his report there is a sketch map with sections showing quite accurately the location of the lowest and highest productive coals. The intermediate and less profitable coals are briefly discussed in the text and are indicated in the section.

In 1891 Mr. Robert T. Hill made a reconnaissance of the western part of the Choctaw coal field.² In his paper Mr. Hill discusses the structure, and locates on his reconnaissance maps the lowest productive coal considered by Dr. Chance.

In 1895 Dr. J. J. Stevenson also investigated the coal field across the southern part of the Choctaw Nation.³ In his publication he correlates the work done by Mr. Hill and Dr. Chance with Mr. Winslow's section of the same rocks in western Arkansas.

In 1896 Dr. N. F. Drake made a general survey of nearly the entire coal field of Indian Territory. In his publication⁴ Dr. Drake maps the limits of the coal fields of Indian Territory, and shows a direct connection between those of Kansas and Arkansas. Although Dr. Drake's work was in the nature of a reconnaissance, he separated the Coal Measures into formations and showed the principal coal beds, with the general stratigraphy and structure.

Maps. The maps accompanying this report are drawn from the surveys recently made by the United States Geological Survey. Quadrangles of nearly the same size, bounded by degree and half-degree lines of longitude and latitude, each having an area of nearly 950 square miles and including a portion of the Five Nations of the Indian Territory, have been surveyed and the maps are being drawn and engraved for publication. Neither corners nor lines of the quadrangles are located upon the ground, and reference to the maps is necessary for their location. It will be observed that the townships are drawn in the correct relative positions in which they occur and that the exact elevations above sea level of the township corners are given. On the ground these township corners are located by iron posts, upon the caps of which are cut the numbers of the four adjoining townships, with the elevation of the bench mark above sea level as shown on the map. The section and quarter-section corners are located by stones or posts, near which trees are marked indicating the adjoining section.

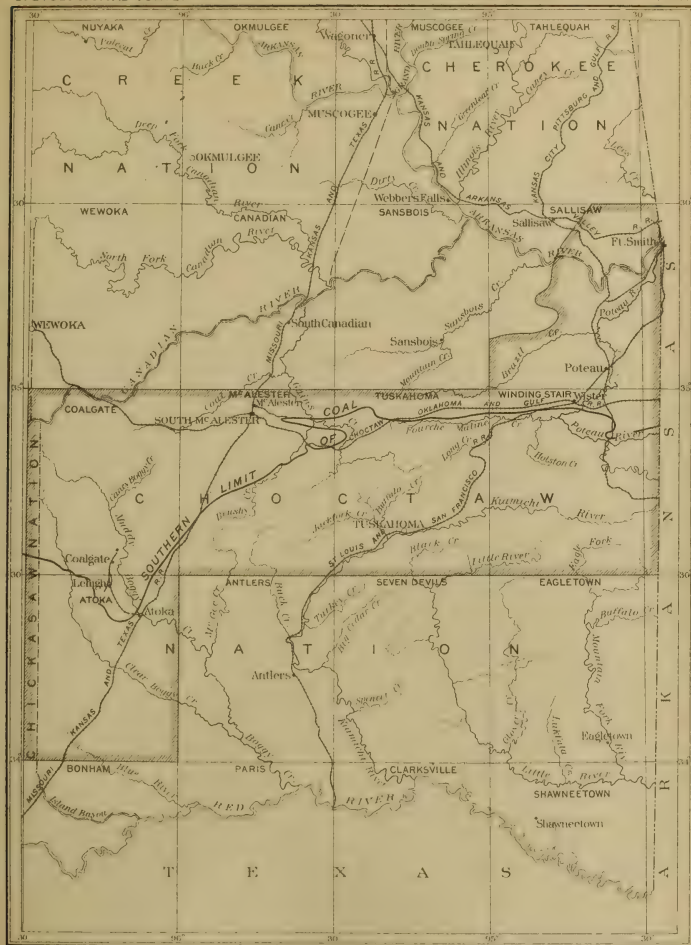
The map of the Choctaw Nation (Pl. XXXV) is introduced to show the southern limit of the Choctaw coal field and the area covered by

¹Geology of the Choctaw coal field. Trans. Am. Inst. Min. Eng., Vol. XVIII, 1890, pp. 653-661.

²Notes on a reconnaissance of the Ouachita Mountain system in Indian Territory: Am. Jour. Sci., 3d Series, Vol. XLII, 1891, pp. 111-121.

³Trans. New York Acad. Sci., Vol. XV, 1895, pp. 50-61.

⁴A geological reconnaissance of the coal fields of Indian Territory, by Noah Fields Drake: Proc. Am. Philos. Soc., Vol. XXXVI, pp. 326-429. Leland Stanford University Publications: Contributions to Biology from the Hopkins Seaside Library, Vol. XIV, 1898.



MAP OF THE CHOCTAW NATION
SHOWING THE SOUTHERN LIMIT OF THE COAL FIELD AND AREA SURVEYED

J. A. TAFF

Scale
0 1 2 3 4 5 6 7 8 9 10 MILES

detailed surveys. On account of the small scale of this map, only the quadrangle boundaries, principal streams, railroads, and towns are shown.

On the map (Pl. XXXVI) drawn to show the structure and location of the principal coal beds the topography is omitted on account of the small scale of the map and in order not to obscure the structure. The quadrangles, township lines, railroads, and principal towns are shown, as aids to the location of the features of structure and of the crops of coal beds. This map includes, together with the map of the Eastern Choctaw coal field, the area of the McAlester-Lehigh coal field reported upon in the Nineteenth Annual Report of the Survey, Part III. This combined map brings together in one view the structure of the entire southern part of the coal region of Indian Territory.

The geologic map (Pl. XXXVII, in pocket) includes parts of six quadrangles—the southern parts of the Fort Smith, Sallisaw, and Sansbois, separated by meridians $94^{\circ} 30'$ and 95° , respectively, and lying north of latitude 35° ; and the northern parts of the Poteau Mountain, Winding Stair, and Tuskahoma, in the same order south of latitude 35° .

Acknowledgments.—The results brought out in this report are in part due to the services of Mr. G. B. Richardson, who assisted in the survey of the geology in the vicinity of Redoak. It is not possible to express the indebtedness of the Survey for the numerous courtesies extended by residents and by those who are interested in mining operations throughout the field. Without exception every request was granted and service was extended by the officials of the mining companies as far as was in their power. Thanks, however, should especially be extended to Mr. L. W. Bryan, United States mine inspector for Indian Territory, and to the superintendents of the mines and other officials of the many companies operating coal.

TOPOGRAPHY.

GENERAL RELATIONS.

The surface configuration of the land is expressed on the geologic map by level or contour lines, each of which throughout its course indicates a definite elevation above the level of the sea. The vertical distance between the positions of any two contiguous contour lines is 50 feet. To aid in determining the elevation of any contour, those at intervals of 250 feet, beginning at sea level, are made heavier and have numbers placed upon them showing their height above the sea. It will be observed that these lines, besides indicating the elevation above sea, also show the positions and true outlines of mountains, hills, and valleys—in other words, the relief or configuration of the land.

Besides indicating the relative positions of the mountains, hills, and valleys, the contour lines show the grade or slope of the land. Where the surface is steep the contour lines fall near together, and where it is nearly level they are widely separated. With the aid of the contour map a discussion of the topography may be understood as readily as if the country itself were in view.

The configuration of the land in this region is a direct result of the wearing away of the rocks by rain and streams. This need not be explained, since any one in the country may see the rains wash the soil into rivulets, and the stream freshets carry it away as mud and sand toward the sea. The progress of this work is very slow, it is true, but it has been going on for a long period of time.

The positions and forms of the mountains, hills, and valleys have been determined chiefly by the structure of the rocks. A reference to the geologic map will show that the upturned edges of the sandstones define the ridges and that all the mountains are located within the broad, shallow synclines.

The area included in the map of the Eastern Choctaw coal field embraces a part of two topographic regions, one of which, the Ouachita Mountains region, begins at the southern border of the Choctaw coal field and coincides with the Ouachita Mountains, which bear west from Arkansas into the southern part of the Choctaw Nation. Only a brief reference to this province will be necessary. The other topographic province is to be known as the Arkansas Valley region, which, as its name indicates, lies along the Arkansas River between the Ozark Plateau on the north and the Ouachita Mountains on the south. Its structure, as well as its topography, is sufficiently distinct from either of the provinces which bound it to entitle it to a distinct name and separate discussion.

OUACHITA MOUNTAINS REGION.

The structure of this province, of which but a narrow strip is shown on the map south of the Choctaw fault, is characterized in Indian Territory by many narrow, closely pressed, and overturned folds, which are broken in a great many places by faults. The folds and principal faults are generally parallel, having an east-west bearing in the eastern part and a northeast-southwest bearing in the western part. Some of them are many miles long, but the greater number are short and occur with lapping or imbricating ends. Thick and hard beds of sandstone and limestone separated by soft shales are upturned in these numerous folds. The shales have been worn down to low, nearly level valleys, while the sandstones and limestones remain in generally parallel, sharp-crested hills, ridges, and mountains. In the central part of the province the folds are widest and correspondingly broad, level valleys and high mountain ridges occur.

ARKANSAS VALLEY REGION.

This province blends with the prairie plains to the northwest. It is bounded upon the north by the foothills of the Boston Mountains, which form the southern limit of the Ozark Plateau. The transition is well marked, being a change from a nearly level plain to an elevated, dissected plateau. The southern limit in Indian Territory is not so clearly defined, since the east-west-trending ridges in the northern part of the Ouachita Mountains region are similar to many of the ridges found in the southern part of the Arkansas Valley region. The great fault above referred to defines approximately the dividing line between the topographic provinces.

Although this fault passes from the hydrographic basin of the Arkansas River southwestward to the drainage of the Red River, a distance of nearly 120 miles, it is throughout its course in low and nearly level valleys. The formation lying along the fault upon the north side is composed of soft rocks and is worn down nearly to a level plain. On the divide between the waters of Fourche Maline and Brushy creeks the plain is so nearly level that it is difficult to discern the direction of the slope. From this low divide the Fourche Maline flows eastward along the fault at a grade of less than 3 feet per mile. The Poteau River meets the Fourche Maline in this valley from the east and flows northward at the same low grade, meandering widely in a broad, level valley. These valleys lying along the fault are parts of the low plain which extends throughout the Arkansas Valley region in Indian Territory and which is known here as the lowland plain.

LOWLAND PLAIN.

Wherever soft rocks occur, and in places where hard beds are steeply upturned in the anticlines, the surface has been reduced by erosion to nearly the same low level. This lowland plain extends around all the mountains and separates the residual ridges and hills of the highland.

The smaller streams are adjusted to the smaller structural features to a considerable degree. They often parallel the monoclinal ridges, cutting their channels along the strike and occupying the outcrops of the softer rocks. Such a stream is James Fork, flowing from east to west along the flank of the Backbone anticlinal region. Owl Creek and the lower portion of Brazil Creek bear a similar relation to the southward-dipping rocks in the broad ridge to the north of them and to the low ridges which are on the flanks of the Sansbois and Cavanal mountains.

These low-level broadened valleys lying between the mountains grade insensibly northward into the greater valley of the Arkansas. The streams of the lowland are corrading their channels very little, and in general are sluggish and are bordered by wide flood plains

which are very little below the general surface of the lowland plain. Poteau River, especially, has numerous meanders and old channels.

Away from the flood plains of the streams, which are heavily timbered, there are small prairies that occupy a large part of the lowland plain. The surface of the prairie land is generally nearly flat, and in rainy seasons very wet. As a result chiefly of this lack of drainage there is produced a peculiar hummocky surface. The hummocks are low mounds but a few feet in height, are oval or circular in outline, and are separated or surrounded by level spaces. The soil of the hummocks is a loose, sandy loam, while that of the surrounding flat surfaces is a more dense clay or sandy clay soil. Usually a clump of bushes upon the hummocks has assisted in the accumulation of mold, thus making the soil more porous. Water passes through the looser soil of the hummocks and collects on the surrounding levels, where the soil is nearly impervious. There are doubtless a number of causes which have assisted in producing this peculiar hummocky form of the level land, but the principal one seems to be the oft-repeated and long-continued accumulation of water in the lower spaces, which dissolves away the more soluble elements of the soil and at the same time makes it more compact.

HIGHLAND PLAIN.

A great number of ridges, hills, and nearly level highlands rise from the lowland plain to elevations of nearly 800 feet above sea level. These crests, therefore, lie practically in a horizontal plane which is considered to have been the general level of the country in recent geologic times. The valleys of the streams lie below it, and above it rise the residuals of the mountains, among which the Arkansas River drainage flows. A few of these mountains have elevations approximating the high levels attained by the principal ridges of the Ouachita Mountains and the Ozark Plateau. The Arkansas River sinks gradually deeper in this plain eastward from the border of the prairie plains. The residual elevated areas which form this highland plain of the Arkansas River Valley may be described as ridges, hills, and mesas or table-lands. Those rising above this plain attain the dignity of mountains and will be so described.

Ridges of the highland plain. The thicker and more resistant sandstones which have been upturned at appreciable angles as a result of folding stand out as ridges, which usually do not rise to heights of over 200 feet. Their crests are nearly level, often for long distances, and extend close to the flood plains of the more prominent streams, whose channels cut across them. The ridges have generally a low slope on the side toward which the rocks dip, the other side, which exposes the edges of the beds, being usually precipitous and sometimes having cliffs at the top.

The arrangement and distribution of these ridges depend upon the geologic structure and the geographic distribution of the beds of sandstone in the lower formations exposed in this region. In the Atoka formation the beds of sandstone are heaviest in the eastern part of the field, and the ridges formed by their outcrops swing in broad, elliptical curves, serving to illustrate upon the surface the great folds into which the strata have been thrown.

Toward the west the sandstone beds disappear irregularly from the formation, and consequently the ridges diminish in number and importance. In the northwestern part of the field, in the Backbone anticlinal region, the rocks of the Atoka formation appear and form a number of sharp ridges, the most conspicuous of which is called the Devils Backbone.

The ridge produced by the Hartshorne sandstone is the most prominent in the southern part of the coal field. With the exception of occasional gaps, where it is cut by streams, it is continuous from Poteau River westward. Between Poteau River and Heavener it is lower than is usual elsewhere, and in places it has been worn down nearly to the level of the lowland plain. West of Heavener, where the sandstone crosses the axis of the Poteau syncline, it becomes nearly horizontal, and forms a pointed, low table-land projecting to the banks of Poteau River. From the Kansas City, Pittsburg and Gulf Railroad eastward this ridge diminishes in elevation until it is lost in the valley of Sugar Creek, south of Poteau Mountain.

Along the southern border of the area mapped as the McAlester shale there are a number of more or less persistent ridges or elongated hills. Although they are usually low and not easily traced, their arrangement indicates that there are a number of thick sandstone beds in the formation. The ridges are not well shown in the topography of the maps, since they are relatively low. In the northern part of the field the sandstone beds in the McAlester shale have changed in character, so that they produce more prominent ridges and hills. A conspicuous ridge, which in its middle portion takes on the structure of a mesa as a result of the lowering of the dip of the rocks, may be seen well defined on the map between Brazil and Milton. Where the dips are steep the ridge is sharp; as the dips become more nearly horizontal the form changes from that of a ridge to a mesa or table-land.

The lower part of the Savanna formation consists of sandstone beds alternating with shales, and where they occur far out on the flanks of the mountains they produce ridges. The most notable of these occurs west of the towns of Cavanal and Poteau, north of Cavanal Mountain and at the eastern base of Sansbois Mountain. A remnant of the lowest sandstone in this formation caps the mesa just east of Cameron.

Between the Backbone Ridge and others parallel with it north of Cavanal and Sansbois mountains and the Boston Mountains north of

Arkansas River the surface is generally at a lower level. However, in areas of horizontal rocks there are remnants of flat-topped hills or mesas, some of which stand upon the edge of the flood plains of the river with their crests in the older plain.

It is not now possible to discuss the history of this highland plain, since but a part of the field in which it occurs has been surveyed. There is, however, some evidence which indicates that in recent geologic time the surface of the region in which this highland plain occurs was more nearly level than at present, having been reduced to a surface of little relief, above which towered the mountains, as they do to-day above the summits of the ridges and the plateaus. The most apparent evidence of this former surface is to be seen in the almost uniformly level crests of the ridges and hills which lie in the highland peneplain. Surveys in the Coalgate, McAlester, and Canadian quadrangles, in the northwest part of the Choctaw Nation, have located the old course of a river which flowed in a wide, meandering, shallow channel but little below the level of the highland plain. This old channel has been traced southeastward from the Canadian River Valley, in the northwest corner of the Choctaw Nation, across the drainage flowing into the Red River, and thence northeastward back to the Canadian River Valley, northeast of McAlester. In places the banks of this old channel may be recognized as low escarpments. Usually, however, the remnants of sand and gravel deposits now left upon the present divides are all that mark its location. Similar upland deposits of sand and gravel are found in the northeastern part of the Choctaw Nation and in the southeastern part of the Cherokee Nation, about 100 feet above the Arkansas River Valley. These deposits in places are 40 feet in thickness and more than 2 miles wide. It would naturally be concluded that a broad and shallow meandering stream which deposited such quantities of fine sand and silt could have existed only in a nearly level plain.

MOUNTAINS.

The mountains of this coal field are all of the same type and have similar detail of surface features. They are all of synclinal structure, and the same formations occur in all four of the mountains in this field and in nearly the same relative position. It is explained later, in the discussion of the structure, that the outlines of these mountains conform to the forms of the synclines which they respectively occupy. Each of the various beds of hard and soft rock has its influence, where it outcrops, in forming particular features of the mountains. Thus it is that the rocks indicate the character of the mountains; and the form and features of the mountains in turn tell their story of the character of the rocks and of the geologic structure.

The mountains are characterized by benches and terraces, which are formed by the eroded edges of alternate hard and soft strata that dip,

usually at a low angle, toward the centers of the masses. In the lower slopes the heavier beds of sandstone form encircling ridges. High up, where the dips are low, they project in abrupt benches, ledges, and cliffs, which are often impassable. The shales, falling away more rapidly, form the terraces and slopes between the benches and cliffs. The streams dissecting the mountains have cut deep trenches, and in places have separated the mountains into knobs and peaks, as in Caval Mountain, or into a mass of high, irregular ridges, as in Sansbois Mountain. The sides of the mountains, knobs, peaks, or ridges, however, all have the bench and terrace type of sculpture.

STRATIGRAPHY.

General relations.—The formations shown upon the map and discussed in this report are of Upper Carboniferous age, as determined by both fossil shells and fossil plants contained in them. From the Hartshorne sandstone upward in the stratigraphic section the formations are coal bearing. By the evidence of fossil plants occurring in the shales associated with the coal beds the Hartshorne or Grady coal is found to belong to the Lower Coal Measures, while the McAlester coal is classed with the Upper Coal Measures.¹

Beds of sandstone and shale in alternating strata occur in regular succession below the Hartshorne sandstone to a thickness of nearly 7,000 feet. These rocks are a part of the Atoka formation. The other portion of the formation is partially concealed by the overthrust of older rocks from the south along the fault. The nature of this fault is explained later under the heading "Structure." While the occurrence of coal is not known in this formation, it has been reported by prospectors in Fourche Maline Valley, south of Wilburton. It is possible that workable coal may be found in it, since the whole formation lies within the Lower Coal Measures. The Atoka formation is considered in this report because of its possible economic importance and its structural and age relations to the coal-bearing rocks immediately above it.

The rocks south of the fault line are not differentiated. They are older, but belong, in part at least, to the same geologic period as the rocks north of the fault. The former are thrown into close and generally overturned folds and probably are much faulted, while the folds of the latter are wide and relatively flat and shallow, as is illustrated in the maps and sections.

The geology of the unmapped area upon the north side of the field and of a small part of the east end adjoining the Arkansas State line is not considered in this report, since the survey was not sufficient to differentiate the rocks.

¹Geology of the McAlester-Lehigh coal field, Indian Territory, by Joseph A. Taff, David White, and George H. Girty: Nineteenth Ann. Rept. U. S. Geol. Survey, Part III, pp. 436-466, 471.

Character of sediments.—The beds of rock whose edges come to the surface in this coal field and are discussed in this report are sandstone, shale, and coal. Shale succeeds sandstone and sandstone follows upon shale repeatedly, with many coal beds interspersed, until there is a thickness in all of nearly 12,700 feet. The lowest bed is in contact with the fault at the south side of the area mapped, and the highest bed is in the crest of Cavanal Mountain (Section G—H, Pl. XXXVII). Farther west, beyond the region here discussed, sandstone and shale beds occur above these rocks to a thickness of many hundred feet; they doubtless once occurred here, but have been removed by the agencies of erosion. Through all these strata there is apparently a regular conformable succession, the beds being parallel, though crumpled or folded. This being true, there is but one interpretation of the manner of their formation, namely, that they were deposited in the sea or other bodies of water as the bottom continually but slowly sank. Off shore, beneath the action of the waves, or in limited shallow basins where the water was not disturbed, the fine material was carried and deposited as mud and became shale. Near shore and in shallow active water sand was transported and laid down and finally became sandstone. In swamps and probably near long stretches of shore vegetable matter accumulated, sinking down into a peaty mass. As the land subsided, this vegetable matter was submerged by the sea and covered by deposits of mud and sand, and after a long period of time became coal. Throughout all the formations occurring in this coal field there is a wonderful regularity in the physical appearance and composition of the sandstones. Without exception they are all composed of finely divided material, no very coarse-grained or pebbly masses being observed. The character of the rocks themselves testifies to the assertions concerning the manner of their formation. In many of the sandstones in this field may be seen ripple marks and other evidences of the action of water in their deposition. In the shales there are thin sheets or laminae of relatively coarse and fine substance, showing changes in the velocity and course of the current or changes in the source of material. In the coal may be seen the fibrous structure of plants, and in the shale in contact with the coal ferns and plant stems are often found bearing all the detail of their original structural beauty.

The rocks of this field all belong to the Coal Measures. West of it limestones which belong to the Lower Coal Measures occur below the Atoka formation. Fossils were not found in the highest rocks here, but in the westward extension of this field, in the northern part of the Choctaw Nation, still higher rocks are found which are included within the Upper Coal Measures.

The division between the Upper and Lower Coal Measures, as determined upon the evidence of fossil plants by Mr. David White, of this

Survey, is at some horizon in the strata between the Hartshorne and McAlester coal beds, presumably near the middle of the McAlester shale.

Besides the remarkable thickness of the rocks as a whole, and the even texture of the sandstones, there is the not less remarkable great extension from east to west of many of the relatively thin sandstone beds throughout the field. The Hartshorne sandstone is an example. This bed or collection of thin beds of sandstone, not more than 200 feet thick, extends westward from the Arkansas State line completely across the Choctaw Nation, a distance of nearly 200 miles, without any known break in outcrop.

Atoka formation.—This formation occurs with irregular width along the southern side of the Eastern Choctaw coal field. Near the State line, on the southeastern side of the field, the formation as far as exposed aggregates a thickness of between 6,000 and 7,000 feet. At intervals of from 1,000 to 1,200 feet in these shales there are four groups of sandstone strata, each of which is nearly 100 feet thick.

As the formation is traced westward it is seen that the lower two groups of sandstone are cut out by the fault. The upper sandstone beds may be traced farther west, to near the central part of the field, but beyond that they are not known to occur. It is presumed, therefore, that they are lenticular in form and are limited in their extent from east to west beneath the surface as well as in outcrop. Near the western end of this coal field, in the Boiling Springs anticline, the formation is exposed to an estimated thickness of nearly 3,000 feet, and in this exposure no rock of consequence except shales was observed. South of the eastern end of the Hartshorne Basin, in the southwestern corner of the field, not more than 300 feet of the formation is exposed between the Hartshorne sandstones and the fault line.

The sandstone beds are brown or light gray and are often thin and slabby, being separated by shaly layers. The shales are very rarely exposed. Where exposed they are seen to be usually bluish clay shales with occasional ferruginous ironstone concretions. Each group of sandstone, where not worn down by active stream erosion, forms a low and nearly level-crested ridge, and the shales are worn down to level valleys and plains.

The extraordinary thickness of this formation may appear peculiar and may be questioned by some who would suggest that there may be duplication in thickness of rocks by faulting. The best estimate of the thickness of the formation was made in the anticline west of Poteau Mountain, where faulting to any appreciable extent would be readily detected. Section G—H, crossing the anticline referred to, as well as the rocks upon the south along the fault line, illustrates the relative positions of the sandstones and shales.

The irregularity in width and form of the outcrop of this formation

is due to the northward overthrust along the great fault which borders the field on the south side and to the irregular folds which limit its outcrop on the north.

Hartshorne sandstone.—An aggregation of brown, gray, and usually thin-bedded sandstones which locally become shaly constitutes this formation. The upper beds are in places thick, and even massive, while the lower ones are generally thin and grade into shale toward the base. In places the sandstone beds are thin and shaly throughout; at others—for instance, in the railroad cut south of Petros switch, on the Kansas City, Pittsburg and Gulf Railroad—the sandstone is separated into three beds, with shale intervals, each containing a thin coal seam. In this railroad cut the following section is exposed:

Section in cut near Petros switch, Indian Territory.

	Feet.
Shaly sandstone, top not seen, exposed	8
Shale with two thin bands of bituminous matter	20
Disintegrated coal and bituminous shale	8
Shaly sandstone	5
Shales	10
Sandstone	30
Shale, light blue	10
Disintegrated coal and shale	6
Blue shale, base not exposed	15

The thickness of this sandstone could not be accurately determined. By measuring the dip and horizontal distance across the outcrops at numerous places estimates were made, which varied from 100 feet to a little less than 200 feet.

The Hartshorne sandstone forms a ridge which has a generally level crest 50 to 200 feet in height, except where it is cut by a water gap or is locally worn by streams which in recent times have been diverted from their course.

This formation shows at the surface in this field in two main lines of outcrop. The most extensive is along the southern side of the field, and is rudely parallel to the fault. The line of outcrop enters this field from the west and curves around the end of the McAlester anticline west of Wilburton. From Wilburton it trends nearly due east for a distance of about 40 miles, where, in the vicinity of Heavener, it turns south and then west in the form of a hook around the east end of the Heavener anticlinal dome. From the south side of this dome the outcrop of the sandstone bears eastward to and beyond the State line, on the southern side of the Poteau syncline.

There are two coal beds associated with the Hartshorne sandstone, known as the upper and lower Hartshorne coals. The upper bed is above the sandstone and is separated from it by a thin bed of shale, which is variable in thickness. Locally this coal bed rests almost upon the sandstone. It properly belongs in and at the base of the McAlester

shale, which overlies the Hartshorne sandstone. The contact line at the top of the Hartshorne sandstone is drawn approximately upon the crop of this coal. The lower Hartshorne coal bed is separated from the upper by nearly 50 feet of sandstone and shaly strata. The occurrence and character of these coal beds are described further on, under the headings "Distribution of coal," "Mining development," and "Composition and adaptability of coals."

McAlester shale.—This formation occupies the largest area of any occurring in this coal field, and its coal beds are the most numerous and the most economically important. On account of the soft nature of its beds, the surface is worn down nearly to a level, and the generally low dips of its rocks permit successful mining of its coal beds in relatively large areas.

The contact line at the base of the McAlester shale is approximately upon the upper bed of the Hartshorne coal. The sandstone and the coals associated with it have been located by prospects at intervals throughout the field. The parting line at the top of the McAlester shale, between it and the Savanna formation, was not located with the same ease and precision as that at the base. There is no coal known at or near the upper limit of the McAlester shale, the prospecting of which would assist in the location of the contact. Where the sandstones of the overlying formation occur in steep slopes, as they do along the south base of Sansbois Mountain north of Brazil Creek, and also north of Fourche Maline and west of Redoak, the talus from them often conceals the lower beds, so that the contact in many places can be only approximately located. Around the east end of Sansbois Mountain and completely around Cavanal Mountain, however, the parting line is so far removed from the mountain that it may be readily and quite accurately determined. The dips of the rocks are low, and each important sandstone bed marks a well-defined ridge or terrace which may be traced with ease.

The McAlester shale is estimated to range from 2,000 to 2,500 feet in thickness. The measurement in the western part of the field gives nearly 2,000 feet and in the eastern part about 2,500 feet of strata. Since the dips are variable both along and across the strike, the estimates for thickness are only roughly approximate.

Several sandstone beds occur in the McAlester shale, but none are continuous, so far as can be determined, throughout the field. As a whole, however, they become generally thicker and more prominent at the surface from west to east. Many of the sandstone beds can be traced several miles, but none can be accurately mapped, even within the limits of their occurrence. These sandstones are generally thin bedded, though locally they are massive and form ridges. Like most other sandstones in the Coal Measures in this field, they are fine grained in texture and brown in color, and are usually hard, but are sometimes

friable, when they are worn down with the shales so that their edges are concealed. Where the sandstone beds are thickest and are not cut down by streams they form low, nearly level-topped ridges. Such ridges occur between Redoak and Wilburton, in the vicinity of Fanshawe, and between Wister and Howe, north of the Choctaw, Oklahoma and Gulf Railroad. In Brazil Creek Valley north of Redoak some upper layers of these sandstones are exposed on the low arch of the Brazil anticline and produce low, irregular hills. North of Brazil post-office and between Cameron and Shady Point some of the sandstone beds are locally much increased in thickness. North of Brazil, especially, one of the sandstones occurs in massive beds, making a wide ridge. The prominence of this ridge, however, is due in part to the structure, the sandstone being nearly horizontal.

The shales of this formation probably aggregate more than five times the thickness of the sandstones, though their natural exposure can rarely be found. The occurrence and areal extent of these shales may be determined with comparative ease and accuracy by studying the soil and the surface configuration of the country. On careful examination of the surface it will be found that the most insignificant sandstone bed makes its presence known by a ridge or rising ground or by its undecomposed talus or débris. The soil of the country above the shale outside of the flood plains of the streams has been produced by decomposition of the rock in place, so that the soil becomes an index to the nature of the rocks beneath. Outside of the immediate stream valleys the shales produce a clay loam and usually form prairie lands. The shade of the McAlester formation, as shown by the prospect drill and other artificial means, as well as by occasional natural exposures by streams, is generally some shade of blue, although black bituminous shales are commonly associated with the coal seams. The shales are always laminated or stratified in thin beds, and vary from bed to bed in the quantity of sandy material they contain.

The coal in the McAlester shale aggregates 8 to 14 feet in thickness and includes three known workable beds, if the upper Hartshorne coal, which is practically upon the contact of the base, be included. This Hartshorne coal has a thickness ranging between 4 and 8 feet. The other two beds occur in shale 40 to 60 feet apart vertically and from 600 to 700 feet below the top of the formation. Each of these coal beds varies in thickness between 2 and 3 feet. They occur in the horizon of the McAlester coal, though it is not known positively whether either of them is a continuation of the McAlester bed. The character of these coal beds is discussed in detail in the following pages under the headings "Distribution of coal," "Mining development," and "Composition and adaptability of coals."

Savanna formation.—This formation is limited to and forms the lower portions of the mountains in this coal field. It outcrops in the

lower slopes and extends from the base well up toward the crests of Sansbois, Poteau, and Sugarloaf mountains. In Cavanal Mountain the formation is limited to the foothills and encircling ridges extending from Redoak around the mountain nearly to Cameron. In each instance the formation lies high in the synclines or structural basins occupied by these mountains. Indeed, the mountains owe their existence to the presence of the sandstones of this and the succeeding formation. By an examination of the topography of the mountains, as represented on the map, the location and presence of each of the prominent sandstones of this formation may be seen in their encircling projecting edges as so many giant dishes or basins, of gradually smaller proportions, stacked one upon another.

The Savanna formation contains three prominent divisions or collections of sandstone beds, having a thickness of from 100 to about 200 feet each and separated by masses of shale and thin sandstone, with two known workable coal beds. The upper division of this series of sandstones is the thickest, being nearly 200 feet thick; its upper strata are locally massive. Toward the base the strata are seen to become gradually thinner and change to shaly sandstone and shale. As may be seen by reference to the map, this sandstone has the most marked effect upon the topography where its ridge encircles the mountains immediately below the upper contact of the formation. The medial bed is the next in importance and thickness and is also a prominent ridge maker. In section this sandstone bed resembles the uppermost one, the thicker ledges being above. Downward the beds grade into shaly sandstone and then into shales. The lowest sandstone, while neither so thick in section nor so prominent as a ridge-forming rock, is not less important, from the fact that it is associated with a prominent coal bed.

The shales of the Savanna formation are separated into two divisions by the medial sandstone bed. The upper of these varies in thickness from 450 to 530 feet, while the lower division ranges from 300 to 450 feet.

The shales of this formation are as a whole more sandy than the shales of the formation below, though they are friable and disintegrate readily, forming valleys and level stretches of country.

Estimates of the thickness of this formation vary from 1,200 to 1,500 feet. It appears to grow thicker from the west toward the east. The lowest estimate was made near the west end, in Sansbois Mountain, and the highest near the east end, in Poteau Mountain. It will be observed by reference to the map that the dips of the rock vary between 5° and 70° . The variation in dip is along as well as across the strike. Under these conditions an approximate estimate of any section may vary as much as 100 feet from the actual thickness.

There are two coal beds occurring within the limits of the Savanna

formation, one in the lower part, almost immediately below the medial sandstone division, and the other very near the top of the upper sandstone division and practically at the top of the formation.

Boggy shale.—To those acquainted with the surface rock of Cavanal and Sansbois mountains the word "shale" doubtless would not seem to be appropriately applied to this formation, because of the great mass of sandstone boulders and talus known to occur in many places on its upper slopes. In spite of the apparent prominence of the sandstone, it makes relatively a very small part of the formation when compared to the shale. The sandstone strata altogether will not much exceed 400 feet, while there is nearly 2,000 feet of shale in Cavanal Mountain, where the formation has its greatest thickness in this field. Excepting one mass of sandstone, which occurs about 400 feet below the crest of Cavanal Mountain, the beds very much resemble those of the formations below in character and composition. They are chiefly thin bedded, brown in color, and of fine texture. The single sandstone referred to is generally massive and has a thickness of nearly 100 feet. In places it is white or a light shade of pink, and resembles very much a consolidated deposit of pure sand. The shale, as in other formations in this field, is rarely well exposed. In the mountains it is usually concealed by sandstone talus and débris. Immediately below the massive sandstone referred to there is about 400 feet of even-textured blue clay shale. This section is exposed at the west end of the main peak of Cavanal Mountain. The lower part of the Boggy shale as well as that above the main sandstone is, on the whole, more sandy, as shaly sandstone and sandy shale are interstratified with the clay shale. Exposures of this shale are very limited in extent. As in the lower formations, the determination of the character of the shaly beds is a matter of interpretation from surface indications of soil and disintegrated rock.

Chiefly because of the structure this formation occurs in four separate areas in this field, viz. in Sansbois, Cavanal, Poteau, and Sugarloaf mountains. In Sansbois Mountain the remnant is about 1,600 feet thick from the base of the shale to the crest of the mountain. In Cavanal Mountain the section is estimated to be about 2,300 feet thick. In Poteau and Sugarloaf mountains remnants from 500 to 600 feet thick remain and form their tops.

In the northwestern part of the Choctaw Nation the Boggy shale is estimated to be nearly 3,000 feet thick, and it is therefore presumed that 500 to 700 feet of it has been removed from above the crest of Cavanal Mountain.

One coal bed is known in the Boggy shale. This occurs about 200 feet above its base. It is mined at the east end and upon the north side of Cavanal Mountain and varies between 3 and 4 feet in thickness. The occurrence of the coal is known by prospects practically

around Cavanal Mountain for a distance of nearly 30 miles. The presence of this coal in Sansbois, Poteau, or Sugarloaf mountains has not been determined.

STRUCTURE.

GENERAL RELATIONS.

The type of structure of the Choctaw coal field is limited on the south side approximately to the occurrence of the coal-bearing rocks. It is characterized by relatively short, shallow, and wide-lapping folds. The synclines or basins on the whole are wider and shallower than are the anticlines or upward-arching folds. This variation may not seem apparent by casual reference to the map and sections on Pl. XXXVII, since the mountains rest in and are formed by the downward-bending strata and the rocks in the arches are worn down to plains and valleys. The section on the line G—H, Pl. XXXVI, illustrates this general characteristic of the folding.

The anticlines near the south side of the field generally are not symmetrical. The strata upon the north dip at steeper angles than those upon the south. In one instance an anticlinal fold is overturned, so that the rocks on both sides dip in the same direction. This being true, the case would be reversed in the synclines, and the rocks have steeper dips on the south side of the folds.

The intensity of the folding decreases from south to north or northwest in the Choctaw coal field. Near the faulted district upon the south the folds are relatively deep and in places overturned, as explained. Northward, toward the interior, the folds decrease until they become wide, shallow undulations. Still farther northwest, yet within the Indian Territory coal field, folds disappear and the rocks maintain regular low northwest dips.

On the map of the Choctaw coal field (Pl. XXXVI) lines are drawn upon the axes or centers of the folds as far as the geologic survey has been carried. The thickness of the lines indicate the relative magnitude of the folds. The crops of the known workable coal beds also are indicated by dot and short dash lines.

FOLDS.

Kiowa syncline.—This is a long synclinal fold which extends from near Gowen, on the western side of this field, to the southwestern end of the Choctaw coal field, west of Lehigh. The location of the axis of this fold is shown on Pl. XXXVI. The syncline is flat and basin-like or spoon-like at each end and is broad and deep near the center, in the vicinity of Kiowa. The east end is known locally as the Hartshorne Basin, because of the extensive mining operations in it at Hartshorne and Gowen, and because it is surrounded by elevated sand-

stone ridges. Fig. 15 (p. 288) is a cross section of this basin a little east of the center. This section, drawn on the natural scale, shows it to be about 4 miles wide and 600 feet deep at this point from the surface down to the coal and sandstone which form its rim.

The surface basin in the end of this syncline is exceptional and is opposite in character to that of the Poteau syncline, its counterpart in the east end of this field, and to others in this region of synclinal mountains and anticlinal basins or plains. The cause of this exceptional feature is that the rocks, with the exception of a few remnants of sandstone capping the mesas and knobs, are all shale or thin sandy beds, which are easily worn down to plains or valleys by erosion. The sandstones of the ridges forming the west side of the basin and those capping the mesas and knobs are the same, and once extended over the basin, forming an elevated land similar to the west end of Sansbois Mountain. As soon as the water courses found their way through the hard sandstones the wearing of the soft shales was more rapid, and the hills, protected by the sandstone on their crests, were gradually reduced until we have the present small remnants of flat-topped hills in the basin.

Poteau syncline.—This is a long synclinal fold which stretches for more than 100 miles along the south side of the Arkansas coal field and extends into Indian Territory for a distance of 12 or 15 miles. It is the counterpart of the Kiowa syncline, which ends in the Hartshorne Basin. Its axis curves northward and ends in the form of a spoon or canoe. The Hartshorne sandstone and shale beds occur here, forming a small basin at the west end of Poteau Mountain, known locally as the Mitchell Basin. Shale and sandstone beds lying beneath the Hartshorne sandstone are also brought up by the syncline, and they may be seen in the ridges curving successively around in the syncline for a distance of 10 miles west of Mitchell Basin and south of the mouth of the Fourche Maline. With the exception of the west end, this syncline is occupied by mountains, which rise to various altitudes, but continue practically as far as the syncline is known.

McAlester anticline.—This anticline enters the field in Gaines Creek Valley, north of the Hartshorne Basin, and ends as a complete fold between the east end of this basin and Wilburton. The north limb of the anticline, however, continues eastward through the south side of this part of the coal field and becomes the north limb or side of the Heavener anticline, which lies immediately north of the Poteau syncline. The south limb of the McAlester anticline, between the Hartshorne and Mitchell basins, is concealed by the overthrust from the south side of the Choctaw fault. By overlooking this loss of a part of the anticline by concealment, the McAlester and Heavener anticlines would be considered as one fold. The original condition of the structure on the south between the ends of the two anticlines is concealed by the fault,



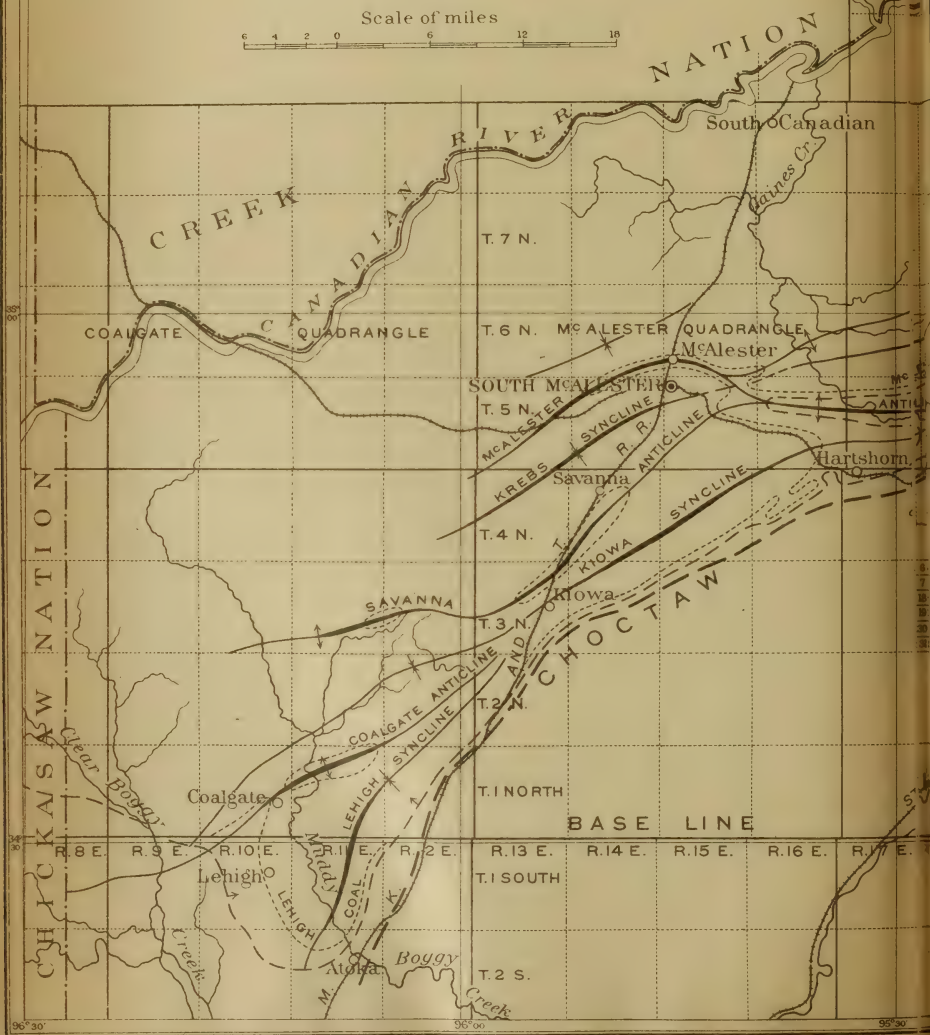
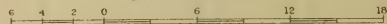
STRUCTURE OF THE CHOCTAW COAL FIELD INDIAN TERRITORY

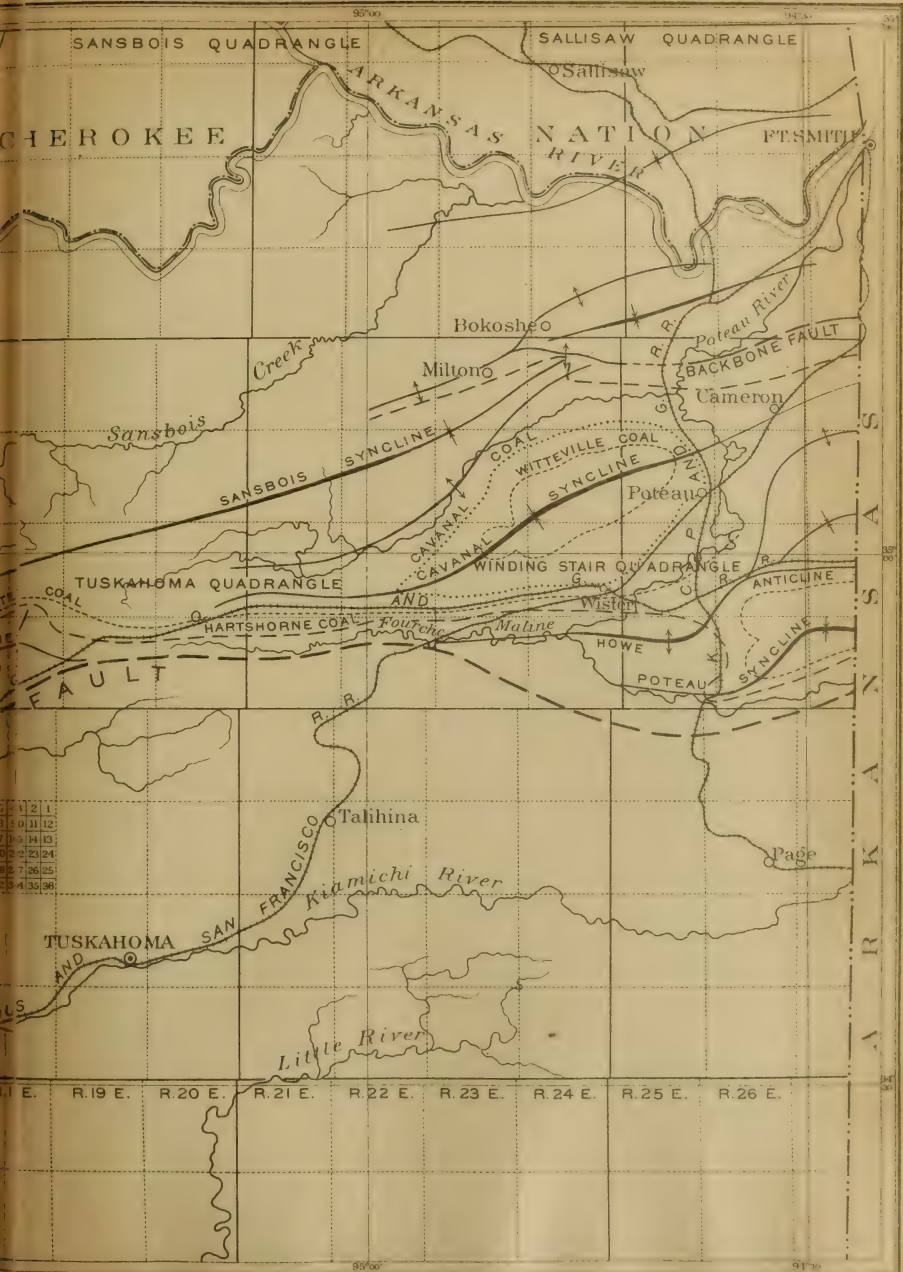
SHOWING AXES OF FOLDS AND CROPS OF PRINCIPAL COAL FIELDS

By Joseph A. Taff

1900

Scale of miles







however, and can not be known, and hence they are regarded as independent structures.

The westward extension of the axis of this anticline passes through Cherryvale, from which place it curves northward through McAlester. Its exact location is shown on Pl. XXXVI.

The fold is not symmetrical. The rocks upon the north side have steeper dips than those upon the south side, and in places they are overturned and faulted.

A peculiar feature of this fold occurs east of Boiling Spring Creek, near the western border of this part of the field, which may be explained by reference to the Hartshorne sandstone. At the edge of the field as mapped, the Hartshorne sandstone, on the northern limb of the anticline, dips nearly 35° . At the head of Boiling Spring Creek the dip increases to 50° ; then for some 3 miles farther east the rocks turn almost upon edge. Beyond this toward Wilburton the same bed curves toward the south, dipping as low as 10° , and thus forming the abrupt termination of a branch or part of the McAlester anticline, with its axis pitching almost directly downward at the end. The main axis of the McAlester anticline is considered to bear eastward beneath the Choctaw fault south of Wilburton, though the rocks on the south side are concealed in the level plain.

Heavener anticline.—This fold is peculiar both in its form of development and in its bearing or course. From near the mouth of Fourche Maline its axis rises rapidly eastward into a high arch and as abruptly descends within a range of 6 miles southwest of Howe. Should the beds of sandstone which have been worn away and whose edges now crop out in the plain around the elliptical border of this dome-like fold be restored, they would form a mountain more than a mile high, 6 miles long, and 3 miles wide. The bearing of the axis in this fold is a little south of east and almost directly in line with that of the Poteau syncline, against which it abuts.

On the northeastern side of the Heavener anticline an anticlinal fold, which may be considered as a branch of the Heavener anticline, bears northeastward through the vicinity of Howe. From the location of Howe, nearly upon its axis, this anticline is known as the Howe anticline. A peculiar relation of the Howe to the Heavener anticline is that their axes do not join, yet the folds are not separated by any indication even of a syncline. It will be observed by reference to the map that the crop of the Hartshorne sandstone southwest of Howe does not bear any indication of the effect of a branch fold. The next sandstone above the Hartshorne, however, diverges from the Heavener anticline near Poteau River and bears northeastward beyond Howe, where it crosses the axis of the Howe anticline and turns southward in the Poteau syncline. Between Howe and Monroe the Howe anticline divides into two folds, one of which bears due east between Poteau and Sugarloaf moun-

tains, while the other turns north between Sugarloaf and Cavanal mountains and then east into Arkansas, north of Sugarloaf Mountain. Both branches of this fold are wide and flat. The valleys occupied by the Howe anticline are eroded in McAlester shale. The grades of the streams are very low and the valleys are practically level planes stretching between the mountains from base to base. The economic bearing of this structure and topography will be brought out under the heading "Distribution of coal."

Sugarloaf syncline.—This is a shallow trough which enters the Choctaw coal field from Arkansas between the two branches of the Howe anticline and is occupied by Sugarloaf Mountain, from which it derives its name. At the State line this fold is not more than 6 miles wide, and the rocks are nearly horizontal, except those forming the outer rim at the north and south bases of the mountains.

Cavanal syncline.—This is a wide, canoe-like trough, with narrowly contracted and shallow ends. The axis of the fold is in the form of an obtuse or flattened S. The west end joins the Sansbois syncline west of Redoak and bears due east about 10 miles; then it turns northward 25° and continues 25 miles through Cavanal Mountain to Cameron. From this point the bearing again becomes nearly east and so continues into Arkansas. The structure of this syncline is illustrated by the three sections E—F, G—H, and I—J, Pl. XXXVII. The first and last of these sections cross the fold near the west and east ends, respectively, and show the narrow and shallow character of the fold, while section G—H illustrates the extreme width and depth of the trough near its center. The outcrop of the formations also shows the form and extent of the basin. The base of the Savanna formation lies sufficiently near the border of the basin to indicate its bearing and form. Its successive hard and soft beds, forming concentric ridges and valleys or benches and terraces around Cavanal Mountain, will illustrate the details of structure.

The adaptability of this structure to successful mining of the several workable beds of coal which crop around the border and in the interior of the basin will be brought out in discussing the distribution of coals.

Brazil anticline.—This is a low fold on which Brazil Creek flows and from which it is named. This anticline separates the Cavanal and Sansbois synclines, and its axis is nearly parallel with that of the former.

The axis rises at an angle of 15° in the side of Sansbois Mountain at the head of Brazil Creek, bears eastward, and then northeastward, parallel with the course of the creek. In the vicinity of Walls the axis pitches downward at a low angle, but rises again opposite the east end of Sansbois Mountain. From this point it bears more eastward north of Brazil post-office, where it joins the Buck Creek anticline.

The depression in the axis of this anticline opposite the east end of Sansbois Mountain is a shallow cross syncline rising and then descending from the Sansbois to the Cavanal synclinal basin.

Sansbois syncline.—This is a relatively long, shallow, and interrupted basin which extends eastward through Sansbois Mountain from the vicinity of Krebs, in the western part of the Choctaw coal field. In the western half of the syncline the rocks upon the south side are steeply upturned and locally faulted, while upon the north side the dips are so low that the synclinal structure is not easily perceived. From near the head of Fourche Maline to the east end of Sansbois Mountain the syncline becomes more symmetrical, the dips upon the north and south sides being nearly the same. Between the sources of Fourche Maline and Brazil creeks the geologic structure is undulating and irregular. While the general form of the syncline is preserved, yet the rocks, especially on the south side, are variable in bearing of strike and degree of dip. This variability is due to the entrance of both the Brazil anticline and the Cavanal syncline into the south side of the Sansbois syncline. The interruption of the peculiar structure in the east end of the McAlester anticline between Boiling Spring and Fourche Maline creeks also causes local steep dips on the south side of the Sansbois syncline. From the source of Brazil Creek eastward the dips of the rocks are regular upon both the north and south sides of the synclines and are about 10° .

From the east end of Sansbois Mountain this syncline contracts rapidly and rises to a narrow and shallow end in the highlands 3 miles south of Bokoshe.

It will be observed by reference to the map (Pl. XXXVII) that the axis of this syncline bears nearly due east from its west end near Krebs to a point opposite the west end of Brazil anticline, where the bearing changes to N. 70° E. and continues thus to its east end.

Milton anticline.—This anticline is a narrow and low fold lying next north of the Sansbois syncline and is named from the town of Milton, which is nearly upon its axis. It bears nearly east-northeast from its west end near McAlester to Bokoshe, where it separates into two folds, the southernmost of which is known as the Backbone anticline and has a bearing nearly due east. The northernmost branch of the fold bears northeast and lies north of the Bokoshe syncline, which separates the two divisions of the Milton anticline. This north branch of the Milton anticline is known as the Redland anticline, from the town of this name located nearly upon its axis, where the Kansas City, Pittsburg and Gulf Railroad crosses the Arkansas River. North of the east end of Sansbois Mountain the Milton anticline rises high enough to expose rocks below the lowest coal near its axis.

Backbone anticline.—The Backbone anticline is the fold which is broken by the Backbone fault. It is joined at the west end by the Milton and Brazil anticlines, as explained above. It is narrow and

flat in the western part. The rocks upon either side dip at angles of from 5° to 10° , while near the axis the beds are almost horizontal. This anticline becomes wider and higher eastward, the dips upon the south side especially changing from 10° to 25° . Where the axis crosses Poteau River the Backbone fault becomes prominent and conceals much of the north limb of the fold. Though this fault extends through the central part of the fold and increases in magnitude eastward to the State line, it does not completely obliterate the structure of the fold. As is explained in the discussion of the Backbone fault, the rocks upon the north side have low dips northward, while those upon the other side dip at very much steeper angles southward.

Bokoshe syncline.—As indicated above, this syncline lies between two branches of the Milton anticline, viz, the Backbone and the Redland anticlines. It is a relatively wide and flat basin running nearly east-northeast from the town of Bokoshe at the west end toward the State line south of Fort Smith. Around the west end of this syncline the rocks dip in toward the axis at nearly 10° . As the same beds are followed eastward along the rim of the basin the dips gradually decrease until they become nearly horizontal, thus forming a flat and shallow trough extending in width from the Backbone fault to the Arkansas River. Only the southwestern part of this fold is shown within the limits of the geologic map (Pl. XXXVII). The axis of the fold as far as known, however, may be seen upon the structure sections accompanying the map, Pl. XXXVI.

FAULTS.

Faults of the rocks in Indian Territory, as far as has been observed, are of one type—thrust faults.

Prior to the occurrence of faults of this type the rocks are usually thrown into folds by forces that are considered to bear in a horizontal direction. If, for reasons which often can not be determined, the forces producing the folding be concentrated along a certain fold and become greater than the rocks can resist, a faulting of the beds is produced, generally parallel with the folding, and the strata upon one side are thrust along the fault plane beyond those of the other side.

The sections accompanying the geologic map (Pl. XXXVII) illustrate the types of folds and faults found in the coal field.

Choctaw fault.—This fault extends from the Indian Territory-Arkansas line west and southwest more than 100 miles, to the southern limit of the Indian Territory coal field. It separates this coal field from the older rocks of the Ouachita Mountain region. Prior to the faulting the rocks lying to the south of the Choctaw fault were closely folded, and in many instances the folds were overturned toward the north. Then, as the pressure which produced the folding continued, the strata broke parallel to the folds and the rocks upon the south

side of the fracture were pushed upward and over those upon the north side.

The vertical displacement of the Choctaw fault increases westward from a few hundred feet at the Arkansas line to several thousand feet at the western border of this field.

Backbone fault.—The faults within the Coal Measures rocks are of limited extent, only one of any importance being known within the eastern Choctaw coal field. This is the Backbone fault, which crosses the Arkansas line upon the north side of Backbone Ridge, in T. 9 N., R. 27 E. It extends in a westerly direction, as may be seen by reference to the map, for a distance of about 15 miles, where it dies out or is lost in the axis of the Backbone anticline. The Backbone fault is an overthrust from the south and is in this respect similar in nature to the great fault on the south side of the field.

The vertical displacement of the rocks by this fault can not be accurately estimated, for the reason that the rocks in contact with the fault upon the north side can not be correlated with the strata upon the south side. The Hackett or Panama coal, which occurs south of the fault, is the lowest coal known in Indian Territory. Should the Bonanza coal, which occurs near the fault upon the north side, prove to be the same as the Hackett coal, the vertical displacement of the rocks due to this fault would be not less than 2,000 feet. Should the Bonanza coal be higher in the series than the Hackett coal the faulting would prove to be relatively greater. As the fault line is traced westward it is seen that lower rocks successively crop out on the north side and higher beds are found in contact with them on the south. Thus the displacement of the beds decreases westward, until west of Poteau River it is but a few hundred feet.

DISTRIBUTION OF COAL.

Seven workable beds of coal are known in the eastern Choctaw coal field. They occur in four different formations, from the top of the Hartshorne sandstone, which is the lowest coal-bearing rock known in Indian Territory, upward to the lower part of the Boggy shale. The thickness of rock between the lowest and highest of these coals is estimated to be nearly 3,600 feet. Besides these coal beds, which are profitably worked, there are a number of others that are thin and have been located, chiefly by prospect drill, in various parts of the McAlester shale and Savanna sandstone.

A knowledge of the geologic structure of the rocks in which coal beds occur and of the combined effects of structure and erosion on the topography or surface configuration of the land is necessary to the most successful economic prospecting and exploitation of the coal. Except to test the thickness and quality of a particular coal bed, the drill need not be called into use in a coal field of this nature. All the

known coal beds are associated with sandstone beds of considerable persistency, which make their presence and location known by more or less elevated hills and ridges. When the interval between such sandstone and coal beds is once established, the crop of the coal may be located as rapidly as the sandstone ridge or outcrop can be traversed. The dip of the sandstone may be determined at almost any point by measurements on its outcropping ledges. The coal beds, on the contrary, usually lying in shale, have their edges worn down and concealed by soil and rock débris. The sandstone and coal near at hand remain nearly parallel. The distance of the coal outcrop from that of the sandstone can be readily estimated when the dip is known. The steeper the dip the nearer together will be the edges of the beds at the surface. The position of the crop of a coal bed being known, a knowledge of the grade and approximate depth beneath the surface throughout its area of occurrence is dependent entirely upon a knowledge of the structure. With such knowledge the availability of the coal for mining, according to its inclination and depth beneath the surface, and the area of coal which may be successfully mined may be known, and a proper estimate may be made for the necessary mining plant and facilities for transportation of the coal. The proper method of mining in a particular locality can be best determined by a study of the structural features of that region.

The occurrence and character of coal in this field are known only so far as it has been prospected or mined. Experience has taught that beds of coal, like beds of any other rock, vary in thickness and character from place to place. Thick beds of coal are known to become too thin to be successfully mined within the range of the working of a single mine. A bed of good quality in some instances changes within a short distance to a bony shale, or shaly beds enter it, so that it is worthless. It has been found, however, that the horizons or stratigraphic positions of the thicker coal beds are usually persistent—that is, wherever a particular coal horizon as established in this field has been examined, coal has been found, though it may vary in thickness, texture, and quality.

In this discussion of the distribution of coal, its horizon or its known stratigraphic position and its availability and area are considered, and it remains for the prospector and miner to determine its thickness and quality.

It should also be borne in mind that the name of each coal bed should not carry with it the idea of exact correlation through the coal field. Each coal horizon as named has been traced across the field by the aid of the outcrops of associated rocks. Most of the beds have been prospected through a large part of the field by prospectors using the drop auger and drill, yet the absolute continuity of a particular bed is known only when mines have been connected by gangways, or test pits by strippings.

HARTSHORNE COALS.

These coals are so named because of their early and most successful mining at the town of Hartshorne, just west of this field, and because of their association with the Hartshorne sandstone.

The Hartshorne coals, of which there are two in this field, occur in the upper part and at the top of the Hartshorne sandstone. This sandstone has been described under the heading "Stratigraphy," and its outcrop in the field is indicated by the map (Pl. XXXVI).

In the Hartshorne Basin.—Only the lower coal in this basin is of workable thickness. The vertical section of the rocks of this basin (fig. 14) shows the relative position and thickness of the Hartshorne coals. Near the center of the basin the lower coal bed is 3 feet 10 inches thick by the drill record. The same coal, worked at the Gowen mine No. 3, in the east end of the basin, varies from 3 feet 6 inches to 5 feet in thickness. That which is considered to be the upper Hartshorne coal is 4 feet thick, but is shaly and worthless. Fig. 15 is a section across the basin, drawn to natural scale, and illustrates the structure. At its center the Hartshorne coal is about 600 feet beneath the surface. The axis pitches from the east end nearly westward and at a low angle for a distance of 2 miles, where it becomes flat, and so continues almost to the west end of the basin. From the Gowen mine the main entry inclines westward at a low grade in the axis of the syncline, and from the sides the coal is brought in by gravity and easy hauling.

The area of the Hartshorne coal in the basin within the limits of the area mapped is about 5 square miles.

In the Sansbois syncline.—In the south side of the Sansbois syncline the Hartshorne coals crop from the western border of the area mapped nearly to Redoak, a distance of 23 miles. As far as is known, both

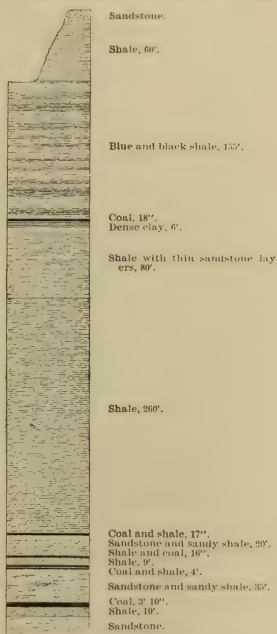


FIG. 14.—Vertical section of coal and associated rocks in the Hartshorne Basin, at the west end of Long Mountain.

beds occur in this syncline. In the mining districts of Wilburton, Ola, and Panola, both coal beds are present in workable thickness, and they probably maintain their character throughout the entire syncline. They are separated by 44 feet of sandstone and shale, and



FIG. 15.—Section across the Hartshorne Basin through Long Mountain. *a*, Hartshorne sandstone; *b*, lower Hartshorne coal; *c*, upper Hartshorne coal. Horizontal and vertical scale the same.

both may be operated by one hoisting plant from either a shaft or a slope.

From the western border of the field to Fourche Maline Valley, a distance of 8 miles, the structure is probably not favorable for extensive and successful mining of the coal. Throughout this distance the rocks dip from 35° to 85° N., and it is possible that local faults occur in the rocks which have the steepest inclination. The strike of these faults would follow approximately the strike of the rocks and could not be readily detected at the surface.

In the Fourche Maline Valley, where the creek enters the plain from Sansbois Mountain, there is a local basin-like structure. The Hartshorne sandstone and coal change in strike from east to south, and then farther on toward Wilburton gradually change to nearly east again. With this change of bearing from east to south, the rock changes in dip from near 50° to as low as 10°, and then to 25° near Wilburton. From Wilburton eastward the structure is regular, with dips toward the north. Along the crop of the coal the dip ranges from 25° to 35°, while from the crop inward toward the axis of the syncline the dip decreases gradually to 10° within a distance of a mile. At the base of Sansbois Mountain the Hartshorne coals are nearly 2,000 feet beneath the surface, as is illustrated in the section C—D, Pl. XXXVII, drawn through the Wilburton mines. The quality of the coals which are mined at Wilburton is indicated by analyses in the table on page 308. It is that of a rather highly bituminous coal, and differs but little from the coal mined at Hartshorne. The area of the coal which may be mined at depths less than 1,000 feet beneath the surface in the south side of the Sansbois syncline is nearly 15 square miles.

The coal bed known as the Panama coal, considered to be in the same horizon as the Hartshorne beds, crops in the north side of the Sansbois syncline, dipping south. The correlation of these two coal horizons is based chiefly upon the determination that each is the low-

est coal in the series of coal-bearing rocks, the one in the faulted Backbone anticline, and the other in the faulted anticline on the southern side of the Choctaw coal field. Each occurs in the same relative position beneath the base of the McAlester shale and at the top of a sandstone of considerable importance, which in both cases is considered to be the Hartshorne sandstone. On the north side of the Sansbois syncline this coal is in places interrupted by shale, but is generally of workable thickness and of splendid bituminous and semibituminous quality. The dip of this bed varies from less than 10° to not exceeding 15° , so far as known. Its area in the north side of the syncline has not been surveyed except on the northeast side of Sansbois Mountain.

In the Cavanal syncline.—Here likewise the Hartshorne sandstone occurs in both the south and north sides, but is of such depth in the fold that it does not pass in outcrop around its ends. Instead, it is tangent to the sides of the elliptical fold, and its outcrop curves southward around the east end of the Heavener anticline south of Howe Station, and then eastward into Arkansas,

in the south side of the Poteau syncline. On the north side of the fold the outcrop continues from the end of the Sansbois syncline nearly due east into Arkansas. The structure of the rocks in this syncline is shown in section G—H, Pl. XXXVII, and the position of the Hartshorne coal in the fold is at the top of the Hartshorne sandstone. The dip at the outcrop on the

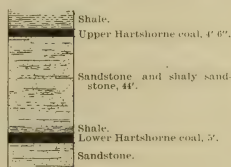


FIG. 16.—Section through mines at the west side of Wilburton.

south side of the syncline ranges from 20° to 35° . In the north side it is 10° to 15° . The dip gradually decreases to 15° on the south side and 10° on the north side of the syncline at the top of the McAlester shale, where the coal is nearly 2,000 feet beneath the surface. In the south side of the syncline nearly 25 square miles may be mined at a depth of less than 1,000 feet, and on the north side nearly the same amount of coal is available within the same depth.

In the south side of the field, between Redoak and Howe, both of the Hartshorne coal beds are present. They have been opened only in prospects, and the thickness and quality appear but little changed from those of the same coal beds mined at Wilburton.

The Panama coal, in the north side of this syncline, especially in the Panama mine, is of higher grade than either of the Hartshorne coals in the south side of the syncline, as above described. It is classed as a semibituminous coal, is low in water, sulphur, and ash, and, as shown by laboratory coking tests, will produce a good grade of coke.

In the Heavener anticline.—The dips of the Hartshorne coals along their outcrop eastward from the vicinity of Pocahontas around the

east end of the anticline change gradually from 40° to less than 10° . Beyond the outcrops of the coals, however, toward the north and northeast, the rocks are subject to different conditions of structure,

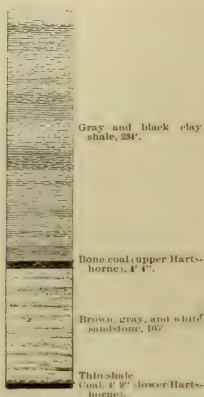


FIG. 17.—Section of rocks at the Potter mine.

which affect the economic importance of the coal. From the outcrop of the coal between Pocahontas and Poteau River the dip of the coals decreases northward at a low rate. From the outcrop between Poteau River and Heavener the dip decreases at a greater rate. In sec. 2, T. 5 N., R. 25 E., for instance, the coals dip 10° at the outcrop. From this locality northeastward toward Howe and along the axis of the Howe anticline the dip of the coal becomes lowest, giving a relatively wide area in which these coals may be mined. Fig. 17 illustrates a section of the rocks, including the Hartsborne coal, at the Potter mine, about 1 mile southwest of Howe Station.

In the Poteau syncline.—The Mitchell Basin, south and southeast of Heavener, is the depressed and flattened end of the Poteau syncline. It has been named for the prospector of the Choctaw, Oklahoma and Gulf Railroad Company, which has leased and prospected this part of the field. In the northwest and west sides of this basin the coals dip southeast and east at 5° and less. From the west and along the south side the dip gradually increases from less than 5° to 25° within 2 miles.

The area of coal that may be successfully mined under existing conditions is nearly 3 square miles.

From the Mitchell Basin eastward to the State line, the crop of the coal lies at the base of Poteau Mountain. The dip through this course varies but little from 25° N.

The most successful mining of the coal south of Poteau Mountain will be by slope, and necessarily but small areas of the coal can be taken by the mining methods now employed in this field.

In the south side of the Choctaw coal field from Pocahontas to the State line but one of the Hartsborne coals has been exploited to any extent. It is considered that the lowest coal is mined at Potter and in the south side of the Mitchell Basin southeast

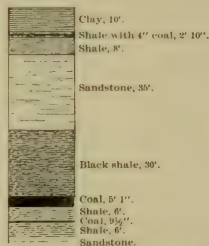


FIG. 18.—Section of coals and associated rocks in the Mitchell Basin.

of Heavener. Numerous bore holes have been sunk in the Mitchell Basin, which show the position of the Hartshorne beds and others of small extent. The section of the rocks here is illustrated in fig. 18.

McALESTER COAL.

There are two beds of coal within the McAlester shale in this field which occur in the stratigraphic position of the McAlester coal as it is known in the Dow, Alderson, Krebs, and McAlester districts, in the western part of the Choctaw coal field. These two coals are separated here by about 60 feet of shale, and lie from 600 to 800 feet below the top of the formation. Below the coal there are a number of sandstone beds which together make low ridges or hills, and which are excellent horizon markers for determining the position of the coal. The dip of the sandstone through the south side of the field is regular and toward the north, and when the position of the coal and its relation to the sandstone is determined, as it is at the Redoak, Turkey Creek, and Fanshawe mines, it may readily be traced throughout its occurrence.

In the Sansbois syncline.—From the south sides of the Sansbois and Cavanal synclines the McAlester coal beds crop in the low and nearly level plain, almost parallel with the Hartshorne coal and sandstone, which occur below and to the south. They have not been mined, and have been prospected but little west of Redoak, hence the thickness and character of the coals are not known.

In the Brazil anticline.—Brazil Creek flows in the center of the Brazil anticline from its source to the vicinity of Walls post-office, its valley being wide and flat. Several hundred feet of the upper part of the McAlester shale are exposed in the sides and bottom of the valley. Rocks in the horizon of the McAlester coal bed occur in the bottom of the creek valley, and several exposures of coal occur in the bed of Brazil Creek. One coal bed 18 inches thick has been mined for local use in Brazil Creek, at the mouth of Jefferson Creek, in the NE. $\frac{1}{4}$ sec. 10, T. 6 N., R. 22 E. Other outcrops of coal in this horizon occur in Brazil Creek north of Redoak.

As far as known, these coal beds are not of sufficient thickness to be mined successfully at the present time. The rocks have low dips toward the north and south in the north and south sides of the valley, respectively. Thus conditions are favorable for successful operation of mines should coals of workable thickness be found.

In the Cavanal syncline.—From Redoak to the Wister district the McAlester coal has been prospected and located at a number of places, and has been mined at Redoak, Turkey Creek, and Fanshawe. The cross section through Redoak (fig. 19) illustrates the structure and positions of the coals. From Redoak to a point opposite the aban-

doned mines at Pocahtonaw the coals crop on the south side of the Choctaw, Oklahoma and Gulf Railroad. Throughout this course the dip is about 10° N. The crop lies south of Wister, in the valley of Mountain Creek. From near the mouth of Mountain Creek east of

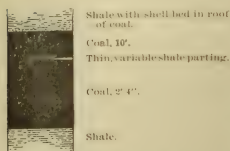


FIG. 19.—Section of coal in the Cavanal mine, $\frac{1}{2}$ mile north of Cavanal Station.

Wister the crop of the coal turns from east to northeast, into the flood plain of Poteau River. In the nearly level valley of Poteau River the dips are low toward the northwest, hence the crop is irregular and can be located only by prospecting. Rocks in the horizon of the McAlester coal outcrop in the northwestern side of the Cavanal syncline from the State line, $2\frac{1}{2}$ miles south of Jenson, westward toward Shady Point. A coal bed has been pros-

spected in the horizon of this coal about 2 miles west of Cameron. Beyond this prospect toward the west the coal is not known north of Cavanal and Sansbois mountains. Its horizon, however, may be located with fair accuracy by taking into consideration the associated sandstone beds, which usually outcrop in ridges and hills of greater or less relief.

In the Poteau syncline.—The McAlester coal horizon occurs at the base of Poteau Mountain, dipping about 20° NW. on the south side, and nearly 10° S. on the north side. Around the west base of the mountain the dip is usually less than 5° E. The thickness and quality of this coal in the Poteau syncline are not known, it having been prospected but little and not at all developed.

Likewise little is known of the McAlester coal in the Sugarloaf syncline in Sugarloaf Mountain. Some prospecting has been done near the horizon of the McAlester coal in the northwestern base of the mountain, but it has not been exploited except for local purposes.

CAVANAL COAL.

In the Cavanal syncline.—In the Cavanal syncline this coal is confined to Cavanal Mountain. It crops a little more than 100 feet stratigraphically beneath the series of sandstone beds which make a line of prominent ridges surrounding the base of the mountain. The prospects $1\frac{1}{2}$ miles north of and at Poteau Station, the mines north of Cavanal Station, and those 3 miles west of Wister are located upon this coal. The contour lines on the map show the ridge made by the sandstone lying above and to the north and west of the mines and prospects referred to. From the mine west of Wister the horizon of this coal strikes nearly due west through secs. 29 and 30, T. 6 N., R. 24 E., secs. 35 to 30, inclusive, T. 6 N., R. 23 E., and in secs. 25 and 26,

T. 6 N., R. 22 E. In sec. 27, T. 6 N., R. 22 E., the strike curves north and then northeast beneath the escarpment of a high ridge. The position of this ridge, as may be seen upon the map, bears northeast and east around the west and north sides of Cavanal Mountain. In the north base of Cavanal Mountain the ridge above the coal is generally worn down, but the sandstone ledges outcrop in many places, and from these the crop of the coal may be easily located.

The Cavanal coal, as far as known, is 3 feet to 3 feet 6 inches thick, is well situated, and structurally disposed for mining. This coal dips beneath Cavanal Mountain at an angle varying from 6° to 20° . The lowest dip is on the southeast side, between Wister and Poteau Station. From Wister westward to Fanshawe the dip gradually increases from 10° to nearly 20° . Beyond Fanshawe and upon the north side of the mountain it is nearly 10° .

From the crop of the Cavanal coal inward toward the mountain the dip changes but little as a rule for a distance of between 2 and 3 miles. Considering the surface to be level and the dip of the rock to be 10° , the coal would descend at the rate of nearly 140 feet for each thousand feet of horizontal distance. The area of the coal in the syncline to a depth of 1,000 feet beneath the crop is nearly 65 square miles.

The proximate analysis given in the table on page 308 is of the coal from the Cavanal mine, three-quarters of a mile north of Cavanal Station. It indicates that the coal is above the average of bituminous grade. The relatively high percentage of sulphur, however, is in the way of its successful use for cooking and some other purposes.

In the Sansbois syncline.—As far as the survey has been carried, the Cavanal coal has not been prospected in this syncline. A coal bed of workable thickness in the stratigraphic position of the Cavanal coal crops out in a branch of Fourche Maline Creek, nearly 4 miles north of Wilburton.

From the head of Brazil Creek eastward the horizon of Cavanal coal gradually descends from the lower slope of Sansbois Mountain into the foothills which surround the base at the east end. The rocks at the horizon of the Cavanal coal in this portion of Sansbois Mountain dip beneath the mountain at angles varying from 10° to 20° . From the west end of Brazil Creek Valley westward to the border of this field the crop of the Cavanal coal lies in the steep lower slopes of Sansbois Mountain, dipping north. On account of the steep slope and the presence of boulders and rock detritus, the sandstone near the coal, as well as that of higher beds, either outcrops as benches or as cliffs or the edges are concealed in the mountain side. In the spur of Sansbois Mountain northwest of Redoak and in the high knob northeast of the same point the rocks in the horizon of this coal dip inward from the sides at angles of 3° and less. On the strike of the coal in the south side of Sansbois Mountain the dip of the rocks increases from 10° in

the vicinity of Redoak to 30° in Fourche Maline Creek. From Fourche Maline Creek westward for 3 miles the dip increases from 30° to 70° , and then decreases rapidly to 30° again, and so continues to the western border of this field.

WITTEVILLE COALS.

There are two beds of coal separated by about 250 feet of shale and sandstone, which will be known as the Witteville coal beds, from the mines upon them at Witteville, in the east end of Cavanal Mountain.

The upper Witteville coal is 3 feet 10 inches thick, separated into two nearly equal benches by a thin parting of shale. This coal has been mined at intervals since 1894, and is delivered to the main line of the St. Louis and San Francisco Railroad at Poteau Station over a branch road belonging to the mining company.

The lower Witteville coal is 4 feet 8 inches thick, and is separated into three benches by two variable bands of bone and carbonaceous shale. It has been opened for exploitation on the crop at the tippie from which the coal from the upper mine is discharged for shipment.

The lower coal occurs at the top of the Savanna formation, while the upper bed is in the lower part of the Boggy shale, about 800 feet and 1,000 feet, respectively, above the Cavanal coal.

The quality of the Witteville coal, as expressed by the proximate analysis in the table on page 308, is nearly the same in all respects as that of the Cavanal coal, the percentages of volatile matter, carbon, and sulphur being a fraction higher, and the ash a little more than 1 per cent less.

In the Cavanal syncline.—The Witteville coal beds are not known in this field outside the Cavanal syncline. The lower Witteville coal being at the top of the Savanna formation, its approximate crop may be located by reference to the contact between the Savanna and Boggy formations as outlined on the map.

The crop of the upper Witteville coal being 250 feet above the base of the Boggy shale, it may be located approximately by reference to the structure of the associated rocks in the syncline and the contact between the Savanna and Boggy formations. Where the slope of the mountain is steep, as at the Witteville mine, the crops of the coals will fall near together. At other places, as upon the northwest and southeast sides of the syncline, where the surface is nearly level, the crops will be more widely separated. The dip of the rocks at the crop of the coal around Cavanal Mountain varies from 6° to 10° . The dip becomes rapidly lower from the crop of the coal toward the center or axis of the syncline, and toward the mountain, so that relatively large areas may be mined by slopes. In the more level areas in the vicinity of Kennady and north of Potato Peaks still larger areas may be worked by shaft.

Section G—H on the map (Pl. XXXVII) illustrates the structure, and fig. 20 gives a vertical column of the coal and rocks of Cavanal Mountain. In the section across the syncline the coals do not descend more than 1,000 feet beneath the level of their crops. From a shaft in the valley near the north line of sec. 12, T. 6 N., R. 23 E., or from one in the valley of Mountain Creek, in sec. 4, T. 6 N., R. 24 E., several square miles of coal can be brought to the hoisting plant by gravity.

The thickness and quality of these coals, however, throughout the lower part of the Cavanal Basin remain to be determined by the prospector.

The area of each of the Witteville coal beds in the Cavanal syncline is nearly 60 square miles.

In the Sansbois syncline.—The Witteville coals are not known to occur in the Sansbois syncline, although the strata in which they belong are present in the high slopes and on the top of Sansbois Mountain. As in Cavanal Mountain, the contact between the Savanna and Boggy formations indicates approximately the horizon of the lower Witteville coal. It awaits the prospector to determine its presence, thickness, and quality. The crop of the horizon of these coals in Sansbois Mountain occurs chiefly in steep slopes and high divides in the dissected mountain, where the surface is generally talus covered. Should these coals occur in the syncline, they would occupy a large area and for the most part would lie nearly horizontal.

In the Poteau and Sugarloaf synclines.—In these synclines only small areas of the formation containing the Witteville coals remain in their crests. Should these coals occur here, they would not be easily accessible, and hence would not have great prospective value.

OTHER COALS IN THE EASTERN CHOCTAW COAL FIELD.

A coal bed reported to be of workable thickness occurs in the Bokoshe syncline nearly 3 miles east of Bokoshe. It has been prospected in the NE. $\frac{1}{4}$ sec. 34, T. 9 N., R. 24 E., where the dip is low toward the southeast. A short distance west of this prospect the

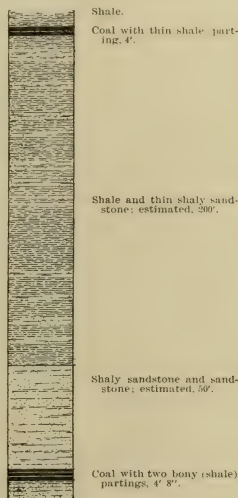


FIG. 20. Section of the Witteville coals and associated rocks at the Witteville mines.

strike changes to south, and then east, around the end of the trough. The width of the basin occupied by the coal will not exceed 2 miles. The survey of the area occupied by the coal is not complete, and further details can not now be given.

MINING DEVELOPMENT.

The data for the following brief discussion concerning operations and output of coal were obtained from the annual reports of the United States mine inspector for Indian Territory, from officials of coal companies, and from observations made during the field work. The summary given in the appended table is not complete in all respects, chiefly because the history of operations and the output of coal of some abandoned mines could not be obtained.

The mining development is discussed by mining districts, considered from west to east, which are naturally divided by conditions of geologic structure and by facilities for transportation.

The development of the eastern part of the Choctaw coal field has been more recent than that of the western. This was caused by the location, in the first place, of the Missouri, Kansas and Texas Railway across the western part of the field in about 1872. Ten years later the St. Louis and San Francisco Railroad was built across the eastern end of the field, but the mining interests of this company were chiefly in western Arkansas, and the development of coal in the Indian Territory was neglected by this company. The Choctaw, Oklahoma and Gulf Railroad from Howe westward, running through the coal field generally parallel with the crop of the coal beds, was built later and opened the western market. The coal in the eastern part of the Choctaw Nation has had to compete with the Arkansas coals, which are generally of better grade and which have been mined extensively. Moreover, the locations of the mines in Indian Territory with respect to railroads are such that their development necessitates the building of branch roads. The Panama bed, for instance, which will be an important source of merchantable coal, crosses the Kansas City, Pittsburg and Gulf and the St. Louis and San Francisco railroads nearly at right angles. Any large development of this coal must therefore be preceded by railway construction connecting with the main lines.

The coal of the Choctaw Nation improves in quality from west to east, and two additional beds are mined in the eastern part that are not known to be productive in the western part. It may confidently be expected, therefore, that the eastern field will surpass the western in importance as a coal producer.

MINING DISTRICTS.

Gowen district.—Gowen is situated in the east end of the Hartshorne Basin and is properly a part of the Hartshorne district. The name Gowen is here applied because it is the only mine in this district upon the map accompanying this report. The coal mined here is the Hartshorne coal, the same that is mined elsewhere in the Hartshorne Basin.

Mine No. 3 of the Choctow, Oklahoma and Gulf Railroad Company is located at Gowen, in the eastern side of sec. 26, T. 5 N., R. 27 E. It was prospected in 1880, but was not worked until 1899. It consists of a shaft 256 feet deep and a slope 3,200 feet distant on the north, which will eventually be connected with the shaft. The coal varies in thickness from 3 feet 6 inches to 5 feet and is clean of shale or other impurities. The dip at the slope is 5° S. The shaft is in the axis of the syncline, which pitches westward at a low inclination and with slight undulations. The main entry is carried westward along the axis of the basin, to which coal from the sides is collected on the main entry by gravity. The company has built a branch road from the main line east of Hartshorne to the mine and has erected a new and commodious hoisting plant at the shaft.

Wilburton district.—The two Hartshorne coals occur at this place, separated by about 50 feet of sandstone and shale.

The McAlester Coal and Mineral Company opened strip pits and a slope in 1895 at a point about $1\frac{1}{2}$ miles west of Wilburton, at the east side of sec. 7, T. 5 N., R. 19 E. The coal here is about 4 feet thick, and dips 12° a little east of north. At this place operations were begun in 1899 by a new company, the Eastern Coal and Mining Company. The McAlester Coal and Mineral Company operated mines in the western part of Wilburton, on the east side of sec. 8, T. 5 N., R. 19 E. At this place in 1897 two slopes were sunk, one on each coal bed, so that the coal could be operated by the same hoisting plant and discharged from the same tippie. The coal in the upper slope is 4 feet 6 inches thick, while that in the lower is 5 feet thick. The dip at these mines is 18° N. The output of the company since 1897 has been principally from these mines.

The Wilburton Coal and Mining Company opened slopes upon both the upper and lower Hartshorne coals in 1897. The slopes are known as No. 1 and No. 2 and are located in the eastern part of sec. 10, T. 5 N., R. 19 E. The upper bed is 4 feet 6 inches thick; the lower is 5 feet thick and is separated from the upper by about 50 feet of sandstone and shale. The dip is 25° N. Mine No. 3 is situated three-quarters of a mile west of Nos. 1 and 2 and is opened on the lower Hartshorne coal.

The bed here is a little over 3 feet thick. This company also has opened mines Nos. 4 and 5 upon the same coals in this vicinity.

The Eastern Coal and Mining Company constructed a branch road in 1899 from the main line of the Choctaw, Oklahoma and Gulf Railroad to a point about $1\frac{1}{2}$ miles west of Wilburton, where they reopened a slope previously operated by the McAlester Coal and Mineral Company. They are now sinking a shaft near this place and will connect with the old workings.

The coal of both the upper and lower beds worked in this district is clean and of highly bituminous quality, as is indicated by the proximate analyses in the table on page 308.

Ola district.—Ola is a siding and small mining town on the Choctaw, Oklahoma and Gulf Railroad, 2 miles east of Wilburton. At this place the Ola Coal and Mining Company operates mines which are known as Slopes Nos. 1, 2, 3, and 4. No. 1 and No. 2 are separated by a distance of 1,400 feet. These slopes are located in sec. 11, T. 5 N., R. 19 E., and are upon the lower Hartshorne coal seam, which is about 5 feet thick and dips N. 25° . Slope No. 2, which is east of No. 1, is upon the upper coal. Slope No. 4, opened in 1899, is located on the west side of sec. 7, T. 5 N., R. 20 E. The coal is from 5 feet to 5 feet 4 inches thick, and is the lower Hartshorne bed. The dip is 35° a little west of north. Like the coal in the Wilburton district, it is clear of shale partings and is of good quality.

Panola district.—The mine at Panola is a slope upon a coal bed cropping 300 feet north of the station, near the east side of sec. 5, T. 5 N., R. 20 E. The mine was opened in 1899 and is as yet but little more than a prospect, the slope being now only 75 feet in depth.

This coal is stratigraphically in the horizon of the McAlester coal, and is so considered by the operators. The bed dips north, is 4 feet 2 inches thick, and is divided in the lower part by 19 inches of shale.

Redoak district.—Two seams of coal were prospected at Redoak in 1899. They are separated by from 60 to 70 feet of shale. These coal beds, which crop just south of the town, are in the SW. $\frac{1}{4}$ sec. 34, T. 6 N., R. 21 E. They are about in the horizon of the McAlester coal, but it is not known that either is its exact representative. The beds are between 2 and 3 feet thick, and have shale contacts both above and below. At present they appear to be clear of shaly impurities, and of good quality. The dip is nearly 10° N.

Turkey Creek district.—The Turkey Creek Mining Company operates 6 miles east of Redoak, near the line of the Choctaw, Oklahoma and Gulf Railroad. The company began operations in 1899 and opened two seams of coal, which are probably the same as the two at Redoak. The mines are at the east side of sec. 34, T. 6 N., R. 22 E. The lower bed is 2 feet 4 inches thick and the upper one is 2 feet 10 inches, and

both occur in shale, as at Redoak. The lower bed has locally a band of bony coal near the base. The dip of the coal here is nearly 20° N. The quality is reported to be good and is successfully exploited. This company also opened one of the Hartshorne beds 1 mile south of its mines and on the line near the quarter corner between secs. 3 and 4, T. 4 N., R. 22 E., and east of Turkey Creek. The coal in this prospect is nearly 4 feet thick and has a sandstone roof. The dip is about 26° N. On the west side of Turkey Creek, in sec. 4, T. 5. N., R. 22 E., another coal bed, nearly 4 feet thick, is prospected and is found to have a shale roof. This coal differs in character from the one on the east side of the creek. It contains local impurities and is termed "faulty" by the prospectors. It is possible that the coal at the former prospect is the lower Hartshorne coal, while this is the upper, though the fact is not definitely established.

Fanshawe district.—The same coal beds which have been prospected and mined in the Redoak and Turkey Creek districts have been opened at Fanshawe, on the south side of the railroad track, but have not been worked for market. The coal beds are in shale and dip north at about the same angle as the coal in the Turkey Creek mines.

Pocahontas district.—The Hartshorne coal was formerly mined at Pocahontas, a station on the St. Louis and San Francisco Railroad, at which place both the upper and lower beds have a workable thickness.

The Kansas and Texas Coal Company opened what was known as the Braidwood mine, near Pocahontas, in the SW. $\frac{1}{4}$ sec. 32, T. 6 N., R. 24 E., in 1890, and worked it for about two years. The mine remained idle from July, 1893, to December, 1894, when operations were resumed for about one year, and then the mine was abandoned. The upper Hartshorne bed at this place is 3 feet 4 inches thick. The lower Hartshorne bed is separated from the upper by about 50 feet of sandstone and shale, as at Wilburton, and is about 4 feet thick. The dip is 45° N. The coal is of good quality, but according to report the steep dip, together with the presence of abundant water and gas, prevented its being worked profitably.

Two miles west of Pocahontas, at a place on the St. Louis and San Francisco Railroad formerly known as Bryan, a mine was opened in 1889 and was operated by the Kansas and Texas Coal Company for about two years. It was located in the SW. $\frac{1}{4}$ sec. 36, T. 6 N., R. 23 E. The coal there is the same as at the Braidwood mine above described.

The quality of the coal in these mines is reported to be of the usual good grade of the Hartshorne coal farther west in this field.

Wister district.—The Cavanal coal has been prospected in the NW. $\frac{1}{4}$ sec. 28, T. 6 N., R. 24 E., and in the NE. $\frac{1}{4}$ sec. 27, T. 6 N., R. 24 E., 3 miles and 2 miles west of Wister Station, respectively. The same coal was found in a well about one-half mile north of Wister.

In the fall of 1899 a company began mining operations by slope on this coal at the prospect 3 miles west of Wister and 500 feet north of the railroad track, the success of which has not been learned.

When examined the coal in the prospect had not been exposed below the level of the disintegrated rock, and its true thickness could not be determined. The coal as exposed, however, was 3 feet thick and dipped 18° N.

Howe district.—The only mine in this district is at the mining camp of Potter, $1\frac{1}{2}$ miles southwest of Howe Station, in the east side of sec. 3, T. 5 N., R. 25 E.

The Mexican Gulf Coal and Transportation Company opened the mine in 1899. The coal is operated by a shaft 110 feet deep and by a slope from the crop of the coal in the ridge to the south. A new shaft, No. 2, 450 feet deep, was begun the same year in advance of the workings.

Mitchell Basin district. In 1899 Milby & Dow sunk a prospect slope on one of the Hartshorne coal beds in the south side of this basin, in the southwest corner of sec. 28, T. 5 N., R. 26 E. The coal is about 3 feet thick and dips 25° N. The high grade of the coal in this basin is attested by the analysis in the table on page 308, which was made from samples collected at this slope.

The Hartshorne coals have been prospected throughout the Mitchell Basin by means of numerous bore holes by the Choctaw, Oklahoma and Gulf Railroad Company, and the whole area underlain by coal is held under lease by this company. The Kansas City, Pittsburg and Gulf Railroad crosses the basin, giving ample facility for shipment, but the company holding the leases has not seen fit to develop the coal.

Cavanal district.—The coal which is mined three-quarters of a mile north of Cavanal Station, in the west side of sec. 17, T. 6 N., R. 25 E., is known as the Cavanal coal seam. The Kansas and Texas Coal Company opened a small mine upon this coal in 1894. In 1897 it produced about 500 tons.

The Crescent Coal and Mining Company began work by reopening the old slope in 1899. It has opened a new mine near by, parallel with the old slope, and constructed a branch road from the main line of the St. Louis and San Francisco Railroad, and has erected a new hoisting plant preparatory to shipping on an extensive scale. The coal at this place is 3 feet 6 inches thick, and shows a thin parting of shale. The dip in the slope is about 7° NW.

The quality is that of a highly bituminous coal, as its analysis, given in the table on page 308, would indicate. Both its sulphur and ash, however, are higher than either the Hartshorne or McAlester coals.

Poteau district.—In the hill on the west side of Poteau Station a

slope was opened on the Cavanal seam, but it has been abandoned. Why this coal was abandoned at this place has not been explained. Presumably it was because a more profitable mine was opened in the Witteville coal in the vicinity.

Witteville district.—At Witteville two seams of coal have been opened. They are known as the upper and lower Witteville beds. The upper Witteville is the coal which was called the Mayberry coal where it was formerly mined north of Cavanal Mountain.

The Cavanal Coke and Railway Company opened the mine at Witteville in 1894, and was reorganized in 1899 as the Indianola Coal and Railway Company. Their mine is a slope on the upper Witteville coal and is located in the eastern base of Cavanal Mountain, in sec. 15, T. 7 N., R. 25 E. The coal is 3 feet 10 inches thick and has a thin shale parting 1 inch to 2 inches thick near its center. The dip at the opening is 6° W., and at the face of the working in the mine is about 3°. The lower Witteville coal has been prospected in the slope of the mountain below the upper Witteville coal, and is found to be $\frac{1}{2}$ feet 8 inches thick, and to contain two considerable shale partings. This coal company has constructed a branch road from its mines to Poteau Station, a distance of 3 miles to the southeast. The coal from the mine is loaded by gravity in railway cars about 1,000 feet distant from the mine.

The analysis in the table on page 308 indicates that this coal is nearly the same in quality as the Cavanal coal. Like the Cavanal coal, also, its structure is weak, but it is shipped successfully to market.

Mayberry district.—The coal which is being operated at the mining town in the west side of sec. 11, T. 7 N., R. 24 E. is the same bed as the upper Witteville coal.

The Choctaw Coal and Mining Company began operations in this mine in 1899. An extensive hoisting plant is being erected at the mine and a branch railway has been constructed to Shady Point, on the Kansas City, Pittsburg and Gulf Railroad. The coal at this mine is $\frac{1}{2}$ feet 6 inches thick, separated by shale into three benches, as follows: Coal, lower bench, 22 inches; shale, 1 inch to 2 inches; coal, 12 inches to 14 inches; coal, upper bench, 16 inches. It dips nearly 9° S.

Jenson district.—Jenson is situated on the St. Louis and San Francisco Railroad just over the State line in Arkansas, about 1 mile south of Backbone Ridge. Reference to it is made here in discussing the mining operations which are near by in the Choctaw Nation. The coal which has been opened near this point is perhaps a continuation of the Hackett coal in Arkansas. In Indian Territory it is known as the Panama coal bed, from developments at the mining town of Panama, on the Kansas City, Pittsburg and Gulf Railroad, farther west. The Jenson Coal Company opened a mine in 1895 about 2 miles west of Jenson.

south of the St. Louis and San Francisco Railroad, in sec. 9, T. 8 N., R. 27 E. The coal is reported to have been faulted and lost, and the mine was therefore abandoned in 1897. The coal is 2 feet 10 inches thick and dips about 12° SSE.

The Kansas and Texas Coal Company has opened a mine known as the Doubleday mine, situated west of the St. Louis and San Francisco Railroad, about 4 miles from Jenson, in sec. 7, T. 8 N., R. 27 E. It was opened in 1895, but was not worked until 1899. The coal has been stripped extensively and is found to run unevenly. In the slope at the face there is 2 feet 4 inches of coal, above which is 7 inches of bony coal, and above this 2 feet 7 inches of coal. The company has erected a temporary hoisting plant and connected its mines to the main line of the St. Louis and San Francisco by a branch road. The operations are carried to considerable depths in order to determine the quality of the coal, and whether or not it may be faulted, before the erection of hoisting machinery and other appliances preparatory to general shipment.

Three and a half miles northwest of Cameron the Panama coal seam has been opened by Mr. C. G. Adkins. The slope is located in sec. 21, T. 8 N., R. 26 E. The seam is 4 feet thick, and is clean coal of splendid quality. It dips 15° a little east of south. This coal is considered by the miners to be the same as one bench of the coal bed at the Doubleday mine. At present this mine is worked in a small way, and the coal is hauled to Cameron for shipment.

Panama district.—The coal mined at this place is considered to be the same bed as that at the Adkins, Doubleday, and Jenson mines, and possibly the Hackett bed in Arkansas. It is known as the Panama coal, its name being taken from the mining town of Panama, on the Kansas City, Pittsburg and Gulf Railroad. The Ozark Coal and Railway Company opened a slope mine in 1899, situated in sec. 21, T. 8 N., R. 25 E., one-half mile west of Panama Station. The coal is of high grade and is clear of shaly impurities. It is 3 feet 10 inches thick, and dips 14° a little west of south.

A branch road from the mine joins the Kansas City, Pittsburg and Gulf Railroad at Panama Station. The company has a new hoisting plant and is shipping coal actively. The coal at present goes chiefly to the Texas market.

Pocola district.—The bed of coal in Arkansas north of Backbone Ridge, known as the Bonanza coal, is thought to continue westward into the Choctaw Nation, and is believed to be the same as that mined in the Pocola district. The Kansas and Texas Coal Company prospected the coal, and did some preliminary work about 1 mile east of Pocola in 1895. The coal is 3 feet 11 inches thick, and dips 10° N. One mile west of Pocola the same coal bed has been worked in a slope, chiefly for local uses. This coal dips about 15° N., is 3

feet 11 inches thick, and has a shale parting 3 inches thick near its center.

Two small slopes were operated in this coal in the vicinity of Pocola by W. O. Hartshorne in 1895. The coal is reported to be 3 feet 10 inches thick, and to dip 10° a little west of north. The total output as reported was 700 tons.

There was some prospecting by the Fort Smith and Western Coal and Railway Company in 1896 at several places near Pocola, but only preliminary work was done.

304 GEOLOGY OF THE EASTERN CHOCTAW COAL FIELD.

Summary of mining operations.

Station.	Location.	Company.	Mine.	Name of coal horizon.
Gowen	Sec. 26, T. 5 N., R. 17 E.	Choctaw, Oklahoma and Gulf Railroad Co.	No. 3 shaft	Hartshorne
Wilburton ..	Sec. 8, T. 5 N., R. 19 E.	McAlester Coal and Mineral Co.	Upper slope ..	Upper Hartshorne.
			Lower slope ..	Lower Hartshorne.
Do.	Sec. 10, T. 5 N., R. 19 E.	Wilburton Coal and Mining Co.	Slope No. 1.	Upper Hartshorne.
			Slope No. 2.	Lower Hartshorne.
			Slope No. 3.	do
			Slope No. 4.	do
Do.	Sec. 7, T. 5 N., R. 19 E.	Eastern Coal and Mining Co.	Shaft	Hartshorne
Ola	Sec. 11, T. 5 N., R. 19 E.	Ola Coal and Mining Co.	Slope No. 1.	Lower Hartshorne.
	Sec. 11, T. 5 N., R. 19 E.	do	Slope No. 2.	do
	Sec. 11, T. 5 N., R. 19 E.	do	Slope No. 3.	Upper Hartshorne.
	Sec. 7, T. 5 N., R. 20 E.	do	Slope No. 4.	Lower Hartshorne.
Panola	Sec. 5, T. 5 N., R. 20 E.		Slope	McAlester
Pedouak	Sec. 3, T. 5 N., R. 21 E.	R. H. Kilpatrick ..	do	do
Do.	Sec. 34, T. 6 N., R. 22 E.	Turkey Creek Coal Co.	Slope No. 1.	do
Fanshawe ...	Sec. 32, T. 6 N., R. 23 E.		slope	do
Pocahontas ..	Sec. 32, T. 6 N., R. 24 E.	Kansas and Texas Coal Co.	Braidwood mine.	Upper Hartshorne. Lower Hartshorne.
Do.	Sec. 36, T. 6 N., R. 25 E.	do	Bryan mine ..	Upper Hartshorne. Lower Hartshorne.
Wister	Sec. 28, T. 6 N., R. 24 E.			Cavanal (?)
Howe.	Sec. 3, T. 5 N., R. 25 E.	Mexican Gulf Coal and Transportation Co.	Shaft No. 1.	Hartshorne
			Shaft No. 2.	do
Heavener ...	Sec. 28, T. 5 N., R. 26 E.	Milby & Dow	Slope	Lower Hartshorne (?) ..
Cavanal	Sec. 17, T. 6 N., R. 25 E.	Crescent Coal and Mining Co.	do	Cavanal
Witteville ...	Sec. 15, T. 7 N., R. 25 E.	Indianola Coal and Railway Co.	do	Upper Witteville ..
Mayberry ...	Sec. 11, T. 7 N., R. 24 E.	Choctaw Coal and Mining Co.	do	do
Jenson	Sec. 9, T. 8 N., R. 27 E.	Jenson Coal Co.		Panama
Do.	Sec. 7, T. 8 N., R. 27 E.	Kansas and Texas Coal Co.	Doubleday slope.	do
Cameron	Sec. 21, T. 8 N., R. 26 E.	C. G. Adkins	Slope	do
Panama	Sec. 21, T. 8 N., R. 25 E.	Ozark Coal and Railway Co.	do	do
Pocola		Kansas and Texas Co.	do	Bonanza
Do.		W. O. Hartshorne ..	do	do
Do.		Fort Smith and Western Railway Co.	do	do

Summary of mining operations.

Thickness of coal.	When opened.	Output, in tons, by years, for years ending June 30—					Total output.	Remarks.
		1895.	1896.	1897.	1898.	1899.		
<i>Fl. in. Fl. in.</i>							<i>Tons.</i>	
3 6 to 5 0	1899					66,741	66,741	
4 6	1897	300	3,000	3,500	16,170	48,062	69,032	[This company's output includes that of a slope operated by the Eastern Coal and Mining Co. since 1898.
5 0								
4 6	1897							
5 0	1897			300	5,575	48,561	53,436	
3 6								
4 0	1895					1,008	1,008	[Opened by the Willburton Coal and Mining Co.; operated by the Eastern Coal and Mining Co. since 1898.
5 0	1897							
5 0	1898			300	8,740	36,880	44,820	
4 6	1898							
5 0 to 5 4	1899							
4 2	1899							
	1899							
2 10	1899							A coal bed 60 feet above this is prospected and proves to be 2 feet 4 inches thick.
								Prospected and mined for local uses.
3 4	1890							[Idle from July, 1893, to Dec., 1894; abandoned in 1896. Output not reported.
3 0								
3 4	1889							[Abandoned in 1892. Output not reported.
4 0								
3 0	1899							
	1899					6,253	6,273	
3 0	1899							
3 3	1899							
4 0	1894	7,989	10,000	23,366	19,605	6,000	55,955	Prospected by the Kansas and Texas Co. in 1894.
	1899							
2 10	1895		3,800	5,500			9,300	Abandoned, 1897.
5 6 to 7 0	1899							Prospected in 1895.
4 0	1899							
3 10	1899							
3 11	1895							Prospect.
3 10	1895	700					700	Small workings; abandoned.
	1896							Prospects.

COMPOSITION AND ADAPTABILITY OF COALS.

Obviously the most satisfactory method of determining the adaptability of a coal is by means of a practical test with the exact conditions under which it is to be used. If, on the other hand, a given quality of coal must be used, then the conditions requisite to its economic utilization should be carefully studied. A proximate analysis, which determines the essential constituents, and a test of the physical properties, are, however, a fair index to the quality of a coal, and if rightly understood will determine to a considerable extent the use to which it is adapted.

The principal uses to which a coal is applied are as a fuel in developing heat, in producing coke, and as a source of illuminating gas. Of these the use as a fuel is by far the largest.

The constituent parts of a coal, as determined by proximate chemical analysis, are: Water, fixed carbon, volatile hydrocarbon, ash, sulphur, phosphorus.

Of these, the fixed carbon and volatile hydrocarbon may be considered as the essential materials. The sulphur, phosphorus, water, and ash are in the nature of impurities. A portion of these may, however, be consumed in combustion. The fixed carbon and volatile hydrocarbon are the fuel portions, and indicate the amount of heat which may be obtained in the combustion. The ratio of the fixed carbon to the volatile hydrocarbon has been called the fuel ratio, and has been taken as the basis for the classification of coals. It is perhaps the most satisfactory method, although there are certain distinctions which it does not express. It is based upon the assumption that the sulphur, phosphorus, water, and ash are accidental impurities, and are liable to vary from place to place and with the method of operating the mine, as well as from conditions affecting it after it has been taken from the ground. For example, the introduction of "slate" or "bony" coal will cause a variation in the amount of ash, while the fuel constituents remain in the same ratio to each other, although forming a smaller percentage of the coal. Two coals thus considered may be of the same quality but may differ as to their impurities.

Besides determining the value of a coal as a fuel the fixed carbon and volatile hydrocarbon are the essential constituents which determine its value in its other uses; namely, in the production of coke and the manufacture of illuminating gas. Coke is a product of fixed carbon and the illuminating gas a product of the volatile hydrocarbon. The coking or fusing of coal is, however, not directly related to its composition, as would seem to be indicated by certain exceptions in which coals do not coke at all, the only safe ground for determining the coking quality being a practical test. In the manufacture of coke the impurities, notably the sulphur and phosphorus, are of vital

importance, since in the subsequent use of the coke in iron smelting the presence of sulphur and phosphorus are highly detrimental. Sulphur occurs in coal as iron pyrites (FeS_2), as sulphate of lime, or gypsum, which appears in thin white scales in the coal, and as free sulphur. In coking the sulphur is largely volatilized and driven off, but if it is in the form of sulphate of lime it will remain in the coke. Methods of crushing and washing the coal are devised for separating the sulphur before it is converted into coke. The sulphur which is in the coke produces in iron which is smelted with it the undesirable quality of red-shortness—that is, the condition of brittleness when hot. Coke should not contain over 1 per cent of sulphur as a maximum.

All of the phosphorus in coal usually remains in the coke produced from it. Its influence upon iron is to produce the condition of cold-shortness—that is, brittleness in a cold condition.

Ash is largely a negative element, with but little chemical influence, unless it is composed of siliceous matter, in which case it will produce clinkers, which are undesirable. The accumulation of the ash displaces the fuel and stops the draft, thus necessitating the frequent cleaning of the fire box. An excessive amount of ash is detrimental in the manufacture of coke and also in the use of the coke in the iron furnace, since it must be disposed of in the slag.

ANALYSES OF COALS.

The following table shows the composition of coals from the Eastern Choctaw coal field. The fixed carbon and volatile hydrocarbon are expressed in the right of the table as percentages of the total fuel constituents, and the fuel ratios are given as the index of the fuel qualities of the coal.

The table of analyses of coals from the McAlester-Lehigh or Western Choctaw coal field is here repeated from the Nineteenth Annual Report of the Survey, Part III, page 456. It is inserted for the sake of comparison, and to this end the fuel ratios have been computed and added to the table.

Table of proximate analyses of coals from the Eastern Choctaw coal field.

[Analyses by George Steiger.]

Name of coal bed.	Location of mine.	Moisture.	Volatile combustible matter.		Ash.	Sulphur.	Phosphorus.	Character of coke.	Fuel constituents.	
			<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>		Volatiles in coke.	Fuel ratio.
Lower Hartsborne.....	West side of Wilburton, Indian Territory.	1.19	37.83	53.06	7.62	1.01	0.023	Lustrous, hard, and slightly swollen.	41.62	38.38
Upper Hartsborne.....	.....do.....	1.43	38.15	50.76	9.46	1.38	.052	.....do.....	42.91	57.09
Hartsborne.....	Potter mine, 14 miles southwest of Howe, Sec. 3, T. 5 N., R. 25 E.	.45	20.89	68.86	9.80	.69	.063	Lustrous, firm, and swollen to several times original volume.	25.28	74.72
Do.....	Two miles southeast of Howe, Sec. 28, T. 5 N., R. 26 E.	.48	22.05	71.28	6.21	1.13	.012	.....do.....	23.61	76.39
Panama (Hartsborne) (?)	Ozark mine, Panama, Sec. 21, T. 8 N., R. 25 E.	.21	15.13	80.00	4.63	1.22	.110	.....do.....	15.90	84.10
Do.....	Douglas mine "Top Vein," Sec. 7, T. 8 N., R. 27 E.	.17	16.33	78.27	3.66	.88	.063	.....do.....	17.44	82.56
Do.....	Douglas mine "Lower Vein".....	.17	15.51	71.01	13.31	1.20	.060	Lustrous, hard, and slightly swollen.	17.93	82.07
Cavendish.....	4 miles north of Cavalad Station.....	.22	23.31	66.16	10.98	1.33	.061	Lustrous, firm, and swollen to several times original volume.	26.24	73.76
Upper Wittreville (Mayberry).	Wittreville mine, Wittreville Station, Sec. 15, T. 7 N., R. 25 E.	.48	23.82	66.69	9.01	4.64	.02	.....do.....	26.32	73.68
Do.....	Mayberry mine, Sec. 11, T. 7 N., R. 24 E.	.55	23.02	64.21	12.22	5.81	.20	.....do.....	26.39	73.61

Table of proximate analyses of coals from the *McAlester-Lehigh* or *Western Choctaw coal field*.

[Analyses by W. F. Hillebrand; sulphur and phosphorus determinations by George Steiger.]

Name of coal bed.	Location of mine.	Moisture in vacuo over H_2SO_4 , 20 to 24 hours.	Volatile combustible matter, loss mois- ture in vacuo.	Ash.	Sul- phur.	Phos- phor- us.	Character of coke.	Color of ash.	Fuel constituents.		
									Volu- tile; car- bon.	Fixed car- bon.	Fuel ratio.
Hartshorne.....	Shaft No. 1, Hartshorne.....	<i>Per ct.</i> 1.68	<i>Per ct.</i> 41.00	<i>Per ct.</i> 5.41	<i>Per ct.</i> 2.72	<i>Per ct.</i> 0.012	Lustrous, with dull-black patches; not swollen.	Reddish brown.....	<i>Per ct.</i> 44.13	<i>Per ct.</i> 55.87	<i>Per ct.</i> 1.26
Do.....	Hughes's mine, 2 miles east of Krebs.	1.04	37.96	5.16	2.00	.012	Dull; slightly swollen.....	.....do.....	40.47	59.53	1.47
McAlester.....	Shaft No. 10, Krebs.....	1.74	37.00	4.40	.65	.014	Lustrous, with black patches moderately swollen.	Light brown.....	39.42	60.58	1.54
Do.....	Sample's slope, 1 mile west of McAlester.	2.08	37.62	4.38	.80	.015	Lustrous; not strongly coherent.	.....do.....	40.11	59.89	1.49
Lehigh.....	Shaft No. 5, Lehigh.....	3.56	41.61	13.71	4.56	.024	Coherent; lustrous.....	Dark reddish brown.....	50.30	49.70	.99

REMARKS BY THE CHEMIST.—The method adopted in obtaining the results given in the above table is that recommended by the committee on coal analyses in a report made to the president and members of the American Chemical Society, and published in the *Journal of the American Chemical Society*, Vol. XXI, No. 12, December, 1899. Moisture is determined by heating 1 gram in a toluene bath ($104^{\circ}C$.) for one hour. The loss by this operation is "moisture." Ash is determined by burning 1 gram until the carbon is gone, and igniting over Bunsen burner to constant weight. To determine volatile matter, 1 gram is heated over Bunsen burner with flame 20 centimeters high for seven minutes. The loss caused by this treatment less "moisture" is "volatile matter." The residue from this treatment is the "coke." The fixed carbon is found by subtracting "ash" from "coke." To determine amount of sulphur, 1 gram is thoroughly mixed with 1 gram of magnesia and a half gram of sodium carbonate. This mixture is heated over an alcohol lamp until all carbon is burned off. The residue is thoroughly leached out with hot water; a small amount of bromine water is added, made acid with hydrochloric acid, and boiled until bromine is gone. Sulphur is then precipitated with barium chloride. A small correction is found in the residue of the water-leach by dissolving in hydrochloric acid, oxidizing with bromine, and precipitating as barium sulphate. Phosphorus is found by burning 5 grams of coal to an ash. This is fused with sodium carbonate, dissolved in nitric acid, and estimated in the usual way by first precipitating with molybdate solution and then with magnesia mixture.

Methods of sampling.—As an aid to the proper appreciation of the value of the proximate analyses of the coals recorded in the table, notes on the method of collecting samples are submitted. The samples from the Panama (Ozark), Cavanal, and Upper Witteville (Mayberry) beds were taken from a number of railway cars, in each case loaded for shipment from the mines. The cars were carefully gone over and a great many specimens collected from both small and large pieces. These specimens were then broken, mixed, and again broken into small fragments. A part of the mixture thus prepared was taken for analysis. The samples from the Doubleday top vein, Doubleday lower vein, and the Mayberry mine were taken from the faces of the workings by first cleaning off the surface of the coal with a hammer and then making a section some 6 inches in width from top to bottom of the vein. The coal thus taken was then broken into small pieces and thoroughly mixed and a sample was taken for analysis. The Lower Hartshorne, Upper Hartshorne and Hartshorne (Potter) specimens were taken at random from mine cars as they were brought from the mine to the tippie, until a large parcel was collected. These specimens were broken, mixed, and divided, and from a division the fragments were again broken and samples taken for analysis. At the Potter mine, where the slope had been driven down about 100 feet, and where several carloads were upon the dump, very many specimens were collected at random, so that an average collection was taken. This collection was then broken and divided and samples for analysis were taken as indicated above. All of these samples were shipped from the field to the office in heavy canvas bags, so it will be observed that the moisture represented in the table of analysis is probably a minimum for these coals.

CLASSIFICATION OF COALS.

According to the variation of their fuel ratios, coals have been classed as exhibited in the following table:

Hard, dry anthracite, ratios varying from.....	100 to 12
Semianthracite, ratios varying from.....	12 to 8
Semibituminous, ratios varying from.....	8 to 5
Bituminous, ratios varying from.....	5 to 0

In this table it will be seen that theoretically the ratios vary from zero to 100, while practically they do not exhibit so wide a range. The classification was made for black or stone coals, and consequently the brown coals or lignites would not be included. In the trade the classes are not strictly observed, but they afford as satisfactory a basis as has yet been proposed.

Considered according to this classification the coals of the Eastern Choctaw coal field are bituminous, having ratios varying between 1.33 and 4.73, with the exception of the coal from the Panama seam at the Ozark mine, which, according to the analysis, has a fuel ratio of 5.32, which places it just within the limit of the semibituminous class.

VARIATION OF COALS.

The coals which are at present mined in a commercial way in the Eastern Choctaw coal field, are found in three horizons. Their geologic occurrence has a wide range, and a variation in the quality of the coal beds may be naturally expected. Only one of the beds, the Hartshorne or Panama, has sufficient geographic range to indicate variation throughout the extent of the field.

Comparing the fuel ratios of the various seams of coal in the region where all of them are closely associated, so as to exclude, as far as possible, variation with their geographic extent, we find that the coal of the Hartshorne seam at Howe has a fuel ratio of 3.29, and at Heavener, 3.23. Its equivalent, the Panama seam at the Ozark mine, shows a ratio of 5.22. The Cavanal seam at Cavanal has a ratio of 2.81. The fuel ratio of the coal from the upper Witteville seam is 2.78, and at the Maberry mine it is the same. This comparison points to the fact that the lower coals have a higher fuel value.

The fuel ratios of the coal from the Hartshorne and Panama seams are seen to be higher in the eastern part of the field. At Wilberton the lower seam has a fuel ratio of 1.40 and the upper a ratio of 1.33. At Howe and Heavener the ratios are 3.29 and 3.23, respectively. The ratio of the lower coal at the Doubleday mine is 4.57 and that of the upper 4.73, while the coal from the Ozark mine at Panama has a fuel ratio of 5.22.

PRELIMINARY REPORT ON THE CAMDEN COAL FIELD
OF SOUTHWESTERN ARKANSAS

BY

JOSEPH A. TAFF

CONTENTS.

	Page.
Introduction	319
Location of the coal field.....	319
Character of the country.....	319
Age of the coal-bearing rocks.....	320
Character of the rocks.....	321
Occurrence and structure of the coal.....	322
Mining development and details of coal sections	323
Composition of the Camden coal	325
Physical properties	325
Chemical composition	325
Table of proximate analyses.....	326
Proximate analyses of air-dried Camden coal	327
Technical analysis	328
Gas-producing qualities of Camden and other coals	329

ILLUSTRATIONS.

	Page
PLATE XXXVIII. Map of part of southern Arkansas, showing the area of the Camden coal field examined	320
XXXIX. Map of the Camden coal field, showing crop of coal and location of mines and prospects	322

PRELIMINARY REPORT ON THE CAMDEN COAL FIELD OF SOUTHWESTERN ARKANSAS.

By JOSEPH A. TAFF.

INTRODUCTION.

The following report is based chiefly upon field work done in May, 1900, although the writer was already somewhat familiar with the region and its geology. The specific object of the report is to describe the mode of occurrence, extent, and economic value of the coal in the vicinity of Camden, on the Ouachita River, Ouachita County, Arkansas. In connection with the examination and mapping of the coal the geology of the associated rocks was investigated as far as possible.

The country has low relief and is densely forested, while the rocks are soft and almost completely covered by soil, so that it would be difficult to make a satisfactory report on the geology of the region, even after a complete survey.

LOCATION OF THE COAL FIELD.

The part of this coal field examined by the writer lies in the north-central portion of Ouachita County, Arkansas, contiguous to the immediate valley of Ouachita River, and to the Camden branch of the St. Louis, Iron Mountain and Southern Railway. It includes nearly 50 square miles, as shown on the sketch map (Pl. XXXVIII). The larger part of this area is in T. 12 S., R. 18 W., where most of the active prospecting and mining has been done. The coal-bearing rocks are exposed east, west, and south from the district examined. Throughout a broad area, which covers parts of several counties, the same coal is reported to occur, but, chiefly on account of facilities for transportation, the Camden field has been more extensively prospected and developed than any other locality in southwestern Arkansas.

CHARACTER OF THE COUNTRY.

The surface of this portion of Arkansas consists of broad alluvial river valleys and a dissected upland. The valleys consist of first and second bottoms bordering the rivers and larger creeks. Their surfaces

are covered by sands and silts deposited by the streams during floods. At present the high waters of these streams cover only a part of the alluvial valley lands, the first bottoms.

The extent of the alluvial lands as represented on the map (Pl. XXXVIII) is adopted from the Annual Report of the Arkansas Geological Survey for 1888, Volume II. So far as the writer's examination extended, the outlines there given are substantially correct.

At the border of the alluvial bottom lands the surface rises rather abruptly, nearly 150 feet, to the general level of the highland. The rocks in the highland are of such a nature that they disintegrate readily, permitting the small streams to cut their way rapidly downward. As a result the surface of the highland, especially near the river, is dissected by a very irregular system of drainage channels. Even the rivulets, by headwater erosion, have cut small gulches in the soft rock, often to their sources.

AGE OF THE COAL-BEARING ROCKS.

In 1859-60 Dr. D. D. Owen made a reconnaissance of the southern counties of Arkansas, during which he examined the geology of Ouachita County. In his report¹ he gives the results of his examination of the coal which occurs in sec. 12, T. 12 S., R. 18 W., and which he calls "the Camden coal."

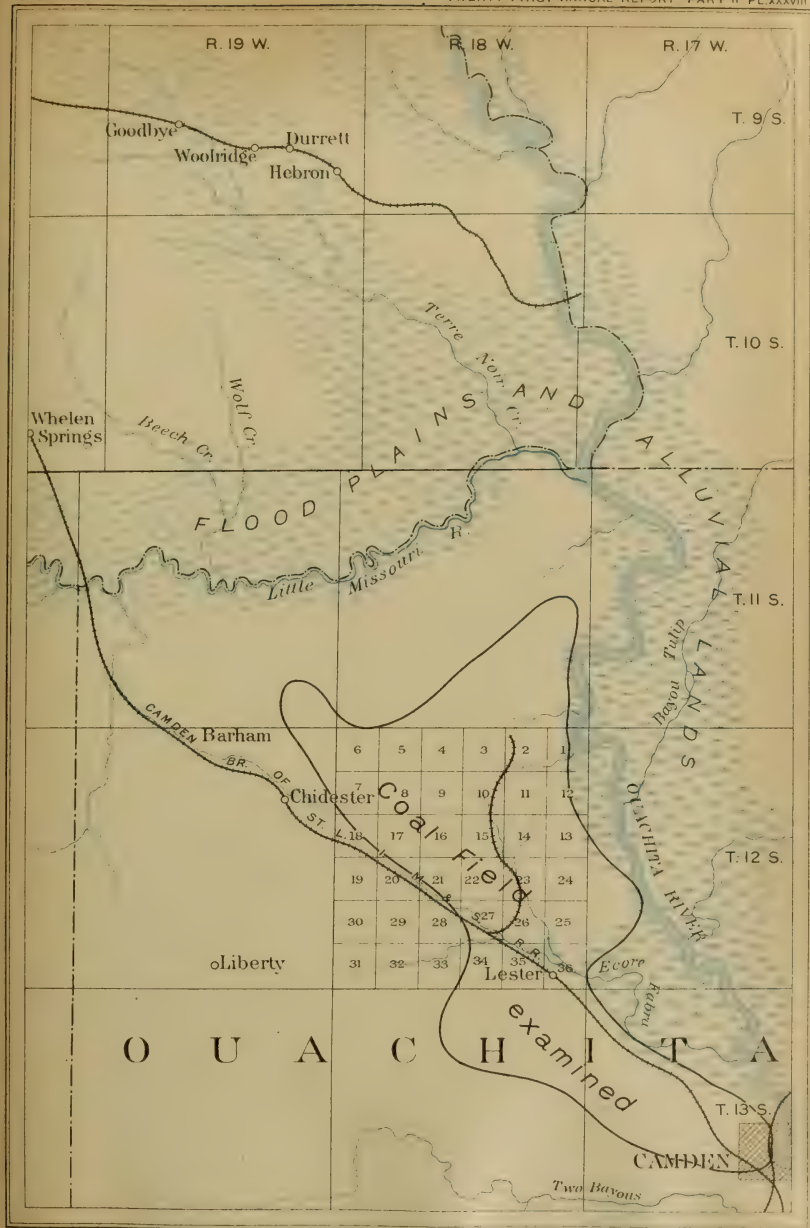
In the Annual Report of the Geological Survey of Arkansas for 1888, Volume II, pages 50-51, Mr. R. T. Hill discusses the geology of the rocks in the region west of Camden and north of Texarkana. Mr. Hill determined that the rocks of the Camden coal field belong to the epoch of the Eocene Tertiary, and calls the coal-bearing formation the Camden series or Camden formation. He states that it extends from Louisiana across southern Arkansas into Texas. He reports the occurrence of lignites or ligneous shales in the bluff of Ouachita River, near Camden, and at the mouth of Little Missouri River. Mr. Hill's work was confined to the valley of Ouachita River in his surveys in Ouachita County, and hence he did not see the Camden coal.

Mr. Gilbert D. Harris published a report on the rocks of Ouachita County in his volume of the reports of the Arkansas Geological Survey.² It was Mr. Harris's object first to determine the age of the rocks by means of the fossil shells which they contain, and then to describe their character. He investigated many localities in Ouachita County, as well as those on the Ouachita River visited by Messrs. Owen and Hill. Mr. Harris visited the mine in sec. 12, T. 12 S., R. 18 W., and reported Owen's section of the coal to be substantially correct.

Mr. Harris verified Mr. Hill's determination of the Eocene age of the coal-bearing rocks of Ouachita County and classified them with the

¹Second Geol. Survey Arkansas, David Dale Owen, Vol. II, 1860, pp. 128-135.

²Ann. Rept. Geol. Survey Arkansas, Vol. II, 1892, pp. 63-78.



MAP OF A PART OF SOUTHERN ARKANSAS
SHOWING THE AREA OF THE CAMDEN COAL FIELD EXAMINED

By J.A. Taft

Scale of miles



1899

Lignitic stage of Mississippi and Alabama. He reports that these coal-bearing rocks form the surface of considerable areas in Dallas, Ouachita, Columbia, Hempstead, Lafayette, and Miller counties, Arkansas.

CHARACTER OF THE ROCKS.

The rocks in the part of the Camden coal field examined by the writer are soft sand and clay shales, except local ferruginous sandstone and ironstone segregations. These sands and clays are compact, but not consolidated. The fresh clays are plastic when wet, and the sands, except where locally indurated, are friable and break down soon after exposure. As a result of these characteristics fresh exposures of rock are exceedingly rare. Occasional cuttings in old roadways, recent excavations at mines, and exposures at some of the numerous springs which issue from the coal outcrop give the only fresh rock exposures.

The following generalized section has been constructed from numerous separate outcrops, from exposures at coal openings, and from the character of soil and partially decomposed rock over the highland. Although far from satisfactory, it is the best that can now be made.

Generalized section of rocks occurring in the Camden coal field, Arkansas.

	Feet.
1. Sand and sandy clays, weathering yellow and red, with local hard beds of ferruginous sandstone and low-grade siliceous iron ore, from the top of the section downward	50 to 60
The sand is more abundant than the clay in these beds, which are best seen in the hilly country along the road between Lester and Camden. The ferruginous sandstones occur in thin, hard plates, and as beds and segregations a foot and less in thickness.	
2. Thin interstratified beds of sand, sandy clay, and clay, yellow to light blue in color	40 to 50
In these strata the sand becomes generally less abundant downward, and at the base there is a bed of clay 4 to 8 feet thick resting upon the coal. This clay above the coal is light blue or ash colored, homogeneous and plastic when wet.	
3. Coal	2 to 3.5
Reported to be in places 6 feet.	
4. Light-gray or bluish clays, not well exposed, reported to be	10 to 20
The clays associated with the coal are partially exposed at the mines in secs. 10, 12, 14, and 25, T. 12 S., R. 18 W.; in secs. 11 and 12, T. 13 S., R. 18 W., and in secs. 7 and 19, T. 12 S., R. 17 W.	
5. From the clay beneath the coal down to the level of Ouachita River bottom the rocks are concealed through an interval of	0 to 30

The rocks are well exposed in the bluffs at the mouth of the Little Missouri, where the river is cutting into the highland, a few miles north of the outcrop of the Camden coal. They are also exposed at Camden, where the river again approaches the highland. The latter locality is south of all the known occurrences of coal in this field.

Having been taken at the only good exposures of the rocks in this region, the sections as given by Mr. Hill¹ are reproduced below.

Section at mouth of Little Missouri River, Arkansas.

	Feet.
1. River alluvium	20
2. Ferruginous conglomerate (Quaternary)	6
3. Thin band of lignitic sand, same character as No. 3 of the Camden section.	
4. Micaceous fine sand	1
5. Alternating lignitic and sandy strata to water level	8

Section of bluff of Ouachita River near Camden, Arkansas.

	Feet.
1. Sandy soil	5
2. Laminated sand with greensand specks, originally white, weathering red ..	32
3. Lignitic shales interstratified with white sand	20
4. Buff-colored micaceous sand and clay, weathering pink and light yellow ..	10
5. Bituminous shales with concretions of iron pyrites, weathering reddish colored	15
6. Fine micaceous sand and clay, laminated	25
7. Concealed strata	25
8. Fine sand and clay similar to No. 6, to water line	10

The Camden coal, without doubt, belongs above the section at the mouth of Little Missouri River, since its northernmost outcrop now known occurs 4 miles farther south and at a higher elevation above the river than the top of Mr. Hill's section. The outcrop of coal nearest the Camden section is that at the Brown mine, 5 miles northwest of Camden. The coal bed can not be traced from this mine to Camden by means of surface outcrops, and hence its position in the section given above has not been accurately determined.

OCURRENCE AND STRUCTURE OF THE COAL.

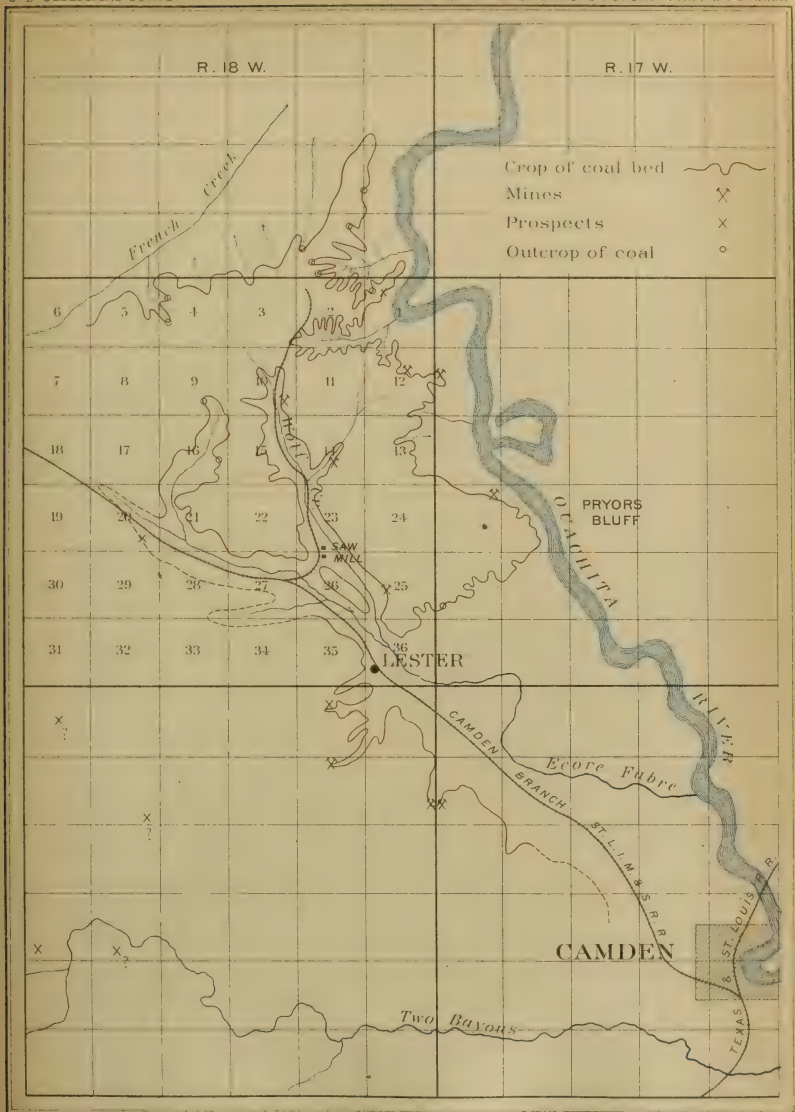
The approximate location of the outcrop of the Camden coal bed is shown on the map (Pl. XXXIX) as it occurs on the east side of the field between the neighborhood of Camden and French Creek.

The Camden coal extends into the highland westward from Ecure Fabre Creek, and is reported to crop out in the valleys at a number of places through western Ouachita County.

Whether or not these isolated outcrops west of the area surveyed are upon the Camden coal was not determined. They are reported by a prospector to be the same in character as the Camden coal and to occur in the same stratigraphic position.

The Camden coal bed and the rocks associated with it when examined locally appear to lie in a nearly horizontal position. When considered over a large area, however, the rocks are found to dip or incline southward, approximately the same as the fall of the Ouachita

¹ Ann. Rept. Geol. Survey Arkansas, Vol. II, 1888, p. 50.



MAP OF PART OF THE CAMDEN COAL FIELD
SHOWING CROP OF COAL AND LOCATION OF MINES AND PROSPECTS
BY J. A. TAFF

Scale of miles

0 1 2 3 4 5

1899



River. At the north end of the field, in sec. 25, T. 11 S., R. 18 W., at the mines in T. 12 S., R. 17 W., and at the Brown mine, in sec. 12, T. 12 S., R. 18 W., the coal outcrops at nearly the same distance above the overflow limit of Ouachita River. Slight undulations or "rolls" occur in the beds, which have no apparent system or regularity of bearing. In places the floor rises and falls without corresponding undulations in the roof, and thus causes local thinning and thickening of the coal.

Mining development and details of coal sections.—The Brown mines are on the east side of sec. 12, T. 13 S., R. 18 W. The coal in the vicinity of these mines crops in the slopes of hills facing Ouachita River bottom, about 40 feet above the overflow line. The coal is being mined in a small way by two drifts which have been driven in about 50 feet. From the entrance of the east drift inward about 40 feet the coal is practically horizontal. Near the face, however, the floor of the coal rises toward the south, causing the coal to change in thickness from about $3\frac{1}{2}$ feet to little less than 3 feet, with clay above and below.

Near the center of the north side of sec. 11, T. 13 S., R. 18 W., a drift, known as the Williams mine, has been opened at the head of a small branch of Ecure Fabre Creek. The mine was closed, and when visited the door was locked, so that an inspection of the coal at the face of the workings could not be made. It is reported by citizens living in the neighborhood, however, that the coal is about $3\frac{1}{2}$ feet thick and occurs in the same manner and is of the same quality as that in the Brown mines. Light-blue and whitish clays several feet thick are exposed above the disintegrated coal at the opening of the mine.

In the NE. $\frac{1}{4}$ of SW. $\frac{1}{4}$ sec. 25, T. 12 S., R. 18 W., Mr. Joseph Dempsey has cut a drift on the coal for about 40 feet. The coal is 3 feet thick, is horizontal, and has a clay roof and floor. In order to give the mine proper drainage the drift was cut in the lower part of the coal and in clays below, so that the full thickness of the coal is not yet exposed.

Near the center of sec. 14, T. 12 S., R. 18 W., two drifts were opened several years ago upon the coal for a distance of 60 feet toward the northeast. The company operating the coal built a branch road nearly 3 miles long from the Camden branch of the St. Louis, Iron Mountain and Southern Railway to the mine. It is reported that on account of insufficient timbering and the presence of water the clay roof gave way and blocked the mine entry and the mine was abandoned. The coal in these mines is said to range from 5 to 6 feet in thickness.

The mine in the NE. $\frac{1}{4}$, sec. 12, T. 12 S., R. 18 W., is the oldest known in this district. The coal at this place was examined and reported upon by Dr. D. D. Owen, State geologist of Arkansas, in

1860.¹ Dr. Owen reported 6 feet of coal in the old mine, which is now closed. A new drift was recently opened beside the old mine to a distance of 50 feet, and the coal at the face of the new mine is 3 feet 6 inches thick. This coal was also examined by Mr. G. D. Harris, of the recent Geological Survey of Arkansas, about 1892. Mr. Harris reports the same thickness of coal as is given by Dr. Owen. The discrepancies between the observations upon the coal section by Messrs. Owen and Harris and by the writer may be explained by the probability that the coal varies in thickness within short distances, caused by the undulations of the clays in the roof or floor of the coal, as above referred to in the Brown mine. At the time the writer visited this mine the clays both above and below the coal were not exposed to the extent reported by Dr. Owen and Mr. Harris.

The mines in secs. 7 and 19, T. 12 S., R. 17 W., were opened a number of years ago and were worked at intervals for some time, but are now abandoned. The coal occurs at practically the same level as that in sec. 12, T. 12 S., R. 18 W., and is reported by the operator to be of about the same thickness and of the same general character. Bluish clays occur at these mines in contact with the coal, as at other mines in this region.

An opening on coal in sec. 2, T. 13 S., R. 18 W., and on the branch road extending southwestward from the lumber mills at Lester Station, is known as the "Bratt prospect." The shaft was sunk about 40 feet and a small quantity of coal was taken out. When visited the shaft was partially filled with water and the coal could not be examined. It is reported by the owner to be about 3 feet thick. Bluish clays were upon the dump and are reported to come from both above and below the coal.

The outcrops indicated on the map (Pl. XXXVIII) are all natural exposures of the coal occurring at springs which issue from the sandy strata above the clay bed overlying the coal. On account of the disintegration of the rocks a full section of the coals could not be obtained at any of these outcrops. The clays are exposed either above or below the coal, and in nearly all of these outcrops the nature of the clays as well as of the coal is found to vary but little from that reported as occurring at the mines and prospects.

The prospects indicated on the map in the western side of T. 13 S., R. 18 W., are provisionally located from information given by a prospector who has worked extensively throughout this part of the Camden coal field.

From the sections of the coal bed observed and reported on good authority it may be safely concluded that it extends continuously throughout the district examined, except where removed by erosion.

¹ Op. cit., 1860.

and that its thickness is at least 3 feet, ranging from that to 6 feet. It is estimated that the single township (T. 12 S., R. 18 W.) in which the bed has been most thoroughly prospected contains over 75,000,000 tons of coal. Of course not all of this can be mined; but even if only half of it is available, the field is capable of sustaining a large output for many years.

COMPOSITION OF THE CAMDEN COAL.

It is necessary to discuss the composition here only so far as it bears on the adaptability of the coal as fuel and for the production of illuminating gas and oil. To this end its physical properties will be considered first, and then its chemical composition.

Physical properties.—The physical properties which have an important bearing upon the use of the coal as a fuel are its color, texture, fracture, hardness, and its power to give out and absorb water under different conditions of exposure.

The Camden coal as it comes from the mine is brownish black and compact and has a generally uniform, even texture or structure. Occasional fragments of lignite with clearly marked woody structure may be seen. It has an uneven, conchoidal fracture. It is soft but not friable; that is, it may be easily mined with a pick and may be cut with a knife as readily as compact dry clay, but it will not crumble between the fingers. When cut or scratched with a knife it shows a shiny or oily streak. Upon being exposed to dry air the coal contracts and cracks, both along the bedding and at right angles to it, so that fragments may be broken by the hand, but the mass does not fall to pieces. The coal is then blacker and harder than when fresh, and the streak or powder is more nearly black. On being exposed for a short time to the repeated action of rain or dew and sun, however, it will disintegrate into small particles. The cracks along the bedding plane bring out the lignitic or woody structure and at the same time make plainer the stratified character of the coal.

The percentage of water contained in the coal as it comes from the mine is expressed in the first column of figures in the table of analyses. The percentage of water in the coal after it is dried in air, the loss in such drying, and the amount of water which the dry coal will absorb in moist air are given in the last three columns of the table, respectively. The water lost in dry air is technically called "hygroscopic water," and it is the loss of this water which causes the coal to shrink and disintegrate on exposure to dry air. Its power to reabsorb and to liberate this hygroscopic water on repeated wetting and drying is the cause of its rapid and complete disintegration when exposed to the weather.

Chemical composition.—A proximate chemical analysis of a coal is that usually made for determining its commercial value. Such an

analysis expresses very nearly the amounts of the various products of the coal which determine its uses and value. These products are: (1) Water, (2) volatile combustible matter, (3) fixed carbon, (4) ash, and (5) sulphur. Of these five substances only the volatile combustible matter and fixed carbon are essential. They form the fuel of the coal, while the other substances are waste. The value of the coal as a fuel depends chiefly upon the percentage of fixed carbon, it being more stable and producing more heat upon oxidation than the volatile combustible matter. The latter includes the combustible gas, oils, and tar of the coal, and is easily kindled and rapidly consumed.

Coals are classified according to the ratio of their fixed carbon to their volatile combustible matter. When this ratio is more than 1 and less than 5—that is, when the percentage of fixed carbon is greater than that of the volatile combustible matter, but less than five times as great—and when the water is less than 10 per cent, the coal is classed as bituminous. When the above ratio is less than 1 and the percentage of water more than 10, the coal is classed as lignite. The greater the ratios between these two products the higher is the grade of the coal.

Instead of aiding combustion the water consumes heat in being evaporated from the coal when the latter is burned. Water, therefore, has a negative value and is an important element in the classification of coals. When the content of water ranges above 10 per cent the coal is usually classed as a brown coal, or lignite.

The sulphur in coals usually occurs in combination with iron, and by its oxidation it aids combustion slightly, but it attacks and corrodes the grate bars and boilers. It is therefore decidedly objectionable, and coals which contain large percentages of it become practically valueless as fuel.

Table of proximate analyses.

No.	Variety of coal.	Locality.	Water	Vola-	Fixed	Ash.	Water—			
			in fresh coal.	tile com- busti- ble mat- ter.	car- bon.		Sul- phur.	Ret- ained in dry air.	Lost in dry air.	Reab- sorbed in moist air.
			<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
1	Brown coal, or lignite. <i>a</i>	Brown mine, Ouachita County, Arkansas.	38.72	36.90	16.90	7.50	0.50	11.23	27.49	b 11.48
2	Brown coal, or lignite.	Sec. 12, T. 13 S., R. 18 W., Ouachita County, Arkansas.	38.00	37.11	19.95	5.85	.42	11.03	26.06	b 11.48
3	Brown coal, or lignite.	Sec. 10, T. 12 S., R. 18 W., Ouachita County, Arkansas.	32.76	32.90	23.32	11.32	.48	9.81	23.09	b 10.25

a Analyses 1-3 made in the laboratory of the United States Geological Survey, by George Steiger.

b In 154 hours.

Table of proximate analyses—Continued.

ANALYSES FOR COMPARISON.

No.	Variety of coal.	Locality.	Water in fresh coal.	Vola- tile com- bus- tible mat- ter.	Fixed car- bon.	Ash.	Sul- phur.	Water—		
								Ret- ained in dry air.	Lost in dry air.	Reab- sorbed in moist air.
			<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
4	Brown coal, or lignite, <i>b</i>	Wood County, Texas.	10.85	37.82	38.21	12.35	.77	6.15	4.70	a 10.25
5	Brown coal, or lignite, <i>b</i>	Milam County, Texas.	16.40	41.52	33.42	7.70	.96	8.70	7.70	a 10.25
6	.....	Nacogdoches County, Texas.	16.82	46.32	31.47	5.37	1.09	7.15	9.67	a 10.25
7	Lignite, <i>c</i>	District of Alberta, northwest Canada.	11.68	35.82	49.88	2.62	.....	4.19	7.49	12.09
8	Lignite coal, <i>c</i>	Lewis River, north-west Canada.	6.03	36.92	49.03	8.02	.....	2.81	3.22	8.80
9	Coal, <i>c</i>	Mill Creek district, Alberta, north-west Canada.	1.63	28.43	57.38	12.37	.....	.38	1.25	2.45
10	Bituminous coal, <i>d</i>	Huntington, Sebastian County, Arkansas.	.92	15.54	77.53	4.84	1.14	Not det.	Not det.	Not det.

a In 154 hours.*b* Geological Survey of Texas, 1892: Brown coal and lignite.*c* On hygroscopicity of certain Canadian fossil fuels: Trans. Royal Soc. of Canada, Vol. VII, 1889.*d* Arkansas Geological Survey, Vol. II, 1888.

Proximate analyses of air-dried Camden coal.

	Water.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
No. 1.....	11.23	44.04	33.69	11.04	0.70
No. 2.....	11.03	47.91	32.81	8.25	.59
No. 3.....	9.81	46.29	29.43	14.47	.63

The samples 1, 2, and 3 of the Camden coal were collected from the fresh faces of the mines, and represent complete sections of the bed. They were transported to the laboratory in air-tight vessels to avoid loss of moisture. The first table gives the percentages of the various constituents of the coal as taken from the mine and containing all of its original moisture, the second table the percentages of the constituents after exposure to dry air for some time. The last represents the composition of the coal as it reaches the market.

In the hygroscopic tests of these coals a unit weight was finely divided and exposed to dry air until it reached a constant weight. This gave loss of water shown in the table under per cent of water "lost in dry air." The percentages of water gained in moist air are the results obtained by exposing the same coal for 154 hours to air

saturated with water. At the end of this time the coal was absorbing water at the rate of 0.2 per cent in 24 hours.

The brownish color of the Camden coal, its conchoidal fracture, its pronounced woody structure in part, and its loss of water and disintegration on drying are the physical properties which class it with brown coal or lignite.

The chemical analyses Nos. 1, 2, and 3 in the first table represent the composition of the coal as it comes from the mine. They show that it contains an unusually high percentage of water and a relatively low percentage of fixed carbon. The amount of sulphur is unusually low, which is in its favor. The percentage of volatile combustible matter is that usually found in the highly bituminous coals.

The low fuel ratio, less than 1 in both the fresh and air-dried samples, and the high percentage of water place this coal below the bituminous grade, and in that of brown coal or lignite. The composition of the air-dried samples corresponds with that of fair-grade brown coals or lignites found in rocks of the same age in Texas and Canada, as shown in the analyses given for comparison in the first table.

From the chemical analyses it is concluded that the Camden coal fresh from the mine would probably not prove successful as a fuel on account of the large quantity of water which it contains. It is believed, however, especially on account of the low percentage of sulphur, that the air-dried coal, if used on specially constructed grates with properly regulated draft, would make a good domestic and steaming fuel.

Technical analysis.—In order to ascertain the gas-producing qualities of the Camden coal a quantity of it was shipped to the Pittsburg Testing Laboratory, Limited, of Pittsburg, Pennsylvania, for testing. The test was made under the following conditions:

The apparatus consisted of a cast-iron retort set horizontally in brick work, heated by natural gas. Connected with the retort was a system of iron tubes which were cooled by contact with the air. In these the tar and water condensed. The gas then passed through about 4 inches of water in a rectangular copper vessel, called the scrubber, and thence to a cylindrical purifier, containing dry slaked lime. It next passed through a gas meter, and was finally collected in a cylindrical holder.

For photometric work a standard sperm candle in a Bunsen photometer was used. The gas was burned at the rate of 5 cubic feet per hour in an Argand burner. Ten readings were taken and the results were averaged. By the use of tables the volume of gas obtained was calculated to standard temperature and pressure. The temperature of the retort was between 1,800° and 2,000° F.

The test was made under the direction of a man familiar with practical gas manufacture.

The quantity of gas obtained per ton of 2,000 pounds of coal was 11,386 cubic feet of 22.3 candlepower.

The following table enables a comparison to be made between the Camden coal and other standard gas coals. The first six coals in the table were tested by the same apparatus under similar conditions and the results are, therefore, strictly comparable.

Gas-producing qualities of Camden and other coals.

No.	Character of coal.	Source of coal.	Cubic feet of gas per ton of coal.	Candle-power of gas.
1	Lignite	Camden, Arkansas	11,386	22.3
2	Bituminous	Washington County, Pennsylvania.	9,880	16.9
3	.....do .....	.....do	9,920	16.1
4	.....do .....	.....do	10,120	18.36
5	Cannel	Beaver County, Pennsylvania.	10,160	22.5
6	.....do	Kentucky	12,540	30.53
7	Bituminous	Upper Monongahela River, Pittsburg Gas Co.	9,500-10,000	16.
a 8	.....do	Silkstone seam, Yorkshire, England.	10,000-11,000	15-17
9	.....do	Newcastle, England. (Average 3 typical coals.)	10,760	16.2
10	.....do	South Yorkshire, England.	11,000	17.
11	.....do	Derbyshire, England	10,500	15.
12	Cannel	Scotch cannel	12,350	31.

a 8-12, Thorpe, Dictionary of Applied Chemistry, Vol. II.

It will be seen from this table that the Camden lignite is superior, both in yield and in candlepower of gas, to the standard bituminous coals of Pennsylvania and England, and that as a gas producer it is inferior only to the best cannel coals.

A RECONNAISSANCE FROM PYRAMID HARBOR TO EAGLE CITY,
ALASKA, INCLUDING A DESCRIPTION OF THE COP-
PER DEPOSITS OF THE UPPER WHITE
AND TANANA RIVERS

BY

ALFRED HULSE BROOKS

CONTENTS.

	Page
Introduction	337
Itinerary	337
Previous explorations.....	340
Geography	344
Coast line.....	344
Orographic features.....	345
Coast Range.....	345
St. Elias Range.....	345
Nutzotin Mountains.....	346
Yukon Plateau.....	346
Drainage	347
Chilkat River.....	347
Alsek Basin.....	348
White River Basin	350
Tanana Basin	351
Fortymile River	353
Physiographic notes	353
Geology	356
Gneissic series.....	356
Kotlo series.....	357
Greenstone schists.....	358
Nutzotin series.....	359
Intrusives	360
Tertiary rocks.....	362
Tok sandstones	362
Tertiary effusives.....	362
Pleistocene deposits	363
Sediments	363
Effusives	364
Glacial phenomena	364
Volcanic tuff.....	365
Ground ice	366
Table of hypothetical correlations	367
Summary of geology.....	368
Mineral resources	373
Gold	373
Porcupine gold district	374
Fortymile gold region	376
Copper	377
Rainy Hollow copper deposits	378
Kletsan copper deposits	379
Tanana-Nabesna copper deposits	381
Development of copper	382
Coal.....	382

	Page.
Routes and methods of traveling	383
Dalton trail	384
Routes to the Upper White and the Upper Tanana	384
Railway routes.....	386
Timber.....	387
Game	387
Climate	388
Inhabitants	388
Natives	388
Whites	390

ILLUSTRATIONS.

	Page.
PLATE XL. Map showing route from Pyramid Harbor to Eagle City, and location of gold and copper deposits so far as determined	338
XLI. <i>A</i> , Pleasant Camp and Jarvis Glacier from Dalton trail; <i>B</i> , Upper Tatshenshini Valley, showing benches along valley slope...	344
XLII. Mountain ranges of Central Alaska.....	346
XLIII. Topographic map showing route from Lynn Canal, via headwaters of White and Tanana rivers, to Eagle City.....	In pocket
XLIV. <i>A</i> , Dissected Yukon Plateau, near camp; elevation about 4,700 feet, looking northwest; <i>B</i> , Dissected Yukon Plateau, near camp, elevation about 4,700 feet, looking north	348
XLV. <i>A</i> , O'Connor Glacier from Slims River Valley; <i>B</i> , Moss-covered plateau in foreground; Mount Natazhat in distance.....	350
XLVI. <i>A</i> , View looking northwest across the Donjek, down the valley of the Koidern River, showing low divide between the Koidern and the Donjek; <i>B</i> , View looking across the Donjek, showing canyon on the right.....	354
XLVII. Geological reconnaissance map of parts of Alaska, British Northwest Territory, and British Columbia	356
XLVIII. Profiles of St. Elias Range and Yukon Plateau, with geology so far as known.....	368
XLIX. Sketch map showing location of Porcupine gold district.....	374
L. Sketch map showing location of Kletsan copper deposits.....	380
FIG. 21. Sketch map showing former drainage channel	355

A RECONNAISSANCE FROM PYRAMID HARBOR TO EAGLE CITY, ALASKA, INCLUDING A DESCRIPTION OF THE COPPER DEPOSITS OF THE UPPER WHITE AND TANANA RIVERS.

By ALFRED H. BROOKS.

INTRODUCTION.

In the spring of 1899 I was detailed to accompany an exploring expedition which was to proceed from Pyramid Harbor, on Lynn Canal, to Eagle City, by way of the headwaters of White and Tanana rivers, and which was to make such surveys along the route of travel as time permitted. The party was constituted as follows: William J. Peters, topographer, in charge; Alfred H. Brooks, geologist; Gastrow S. Phillip, topographic assistant; and Thomas M. Hunt, Ed. Brown, and Joseph Cahill, camp hands. To Mr. Phillip and to the three camp hands Mr. Peters and I wish hereby to acknowledge our indebtedness, for the success of our expedition was in a large measure due to the untiring and faithful service rendered by these four men.

The following report is only a hasty summary of the results of our investigations. A prolonged illness and the stress of other work has prevented me from working up the field notes in detail. The facts that much of the region is so little known and that there is at the present time much interest in the copper deposits are believed to be sufficient excuse for publishing an incomplete report. It has been my aim to give such facts and conclusions as may be of practical value rather than to attempt a technical treatment of the large amount of matter on hand.

ITINERARY.

The party assembled at Pyramid Harbor on May 21, and five days later started inland. One hundred days' provisions and the equipment were packed on 15 horses, while the 6 members of the party walked (see Pl. XL, XLIII). Our route lay up the broad valley of the Chilkat as far as the Indian village of Klukwan, just north of which runs the present (1900) provisional boundary line between the United States

and the Canadian possessions. At Klukwan our course turned westward up the Klehini River, a west fork of the Chilkat, and on May 28 we reached Pleasant Camp, some 40 miles from the coast. A Canadian custom-house and the Northwest mounted police post are situated there, which was then (1899) considered the conventional international boundary. The spring of 1899 was unusually late, and we were forced to wait at Pleasant Camp about three weeks before the trail opened.¹ A part of this time was spent in studying the geology of the neighborhood, but the presence of considerable snow made traveling difficult and rendered the work unsatisfactory, because so many of the outcrops were covered.

On June 21 we left Pleasant Camp by the Dalton trail, which, leaving the Klehini River, crosses a high spur and then descends again to Rainy Hollow, at the headwaters of the same river. Here a delay of a day to rest our horses enabled me to pay a hasty visit to some newly discovered copper deposits in the neighborhood.

Beyond Rainy Hollow the trail crosses a divide to a tributary of the Chilkat and then leads across a second divide to the headwaters of the Chilkat. Beyond that it leaves the Lynn Canal drainage and descends to the Tatshenshini River, an east fork of the Alsek.

On June 25 we reached the Tatshenshini River, at a point opposite Dalton House. Here a day was spent in ferrying our outfit across the river in Indian canoes and in swimming our horses. At Dalton House there is a trading post, a Northwest mounted police post, and near at hand a large Indian village.

On June 30 we left the post, and with it left behind us the last vestige of civilization. Up to this point we had followed the Dalton trail, but this now turned northward toward Lake Dezadeash. Continuing in a westerly direction, we reached the Kaskawulsh River, a west fork of the Alsek, on July 15.² Two days were spent here in building a boat and in getting the outfit and horses across the river.

On July 17 we crossed the moraine of the O'Connor Glacier,³ which occupies a divide between the Alsek and White River waters and which drains in both directions. Two days later we reached the upper end of Lake Kluane, where we were forced to build another boat for ferrying across the Slims River. Our route led us along the shores of the lake for several days, and we then crossed a low divide to the Donjek River, which we reached on July 31. The fording of this turbulent stream proved a difficult and dangerous task and threatened

¹ We are indebted to Dr. S. M. Frazer, of the Northwest mounted police, for many kindnesses shown us during our delay at the post, of which he was in command.

² On the Kaskawulsh we met Messrs. D. D. Garvey and J. J. Haley, two prospectors who had come from Yakutat Bay. We are indebted to them for much information about the country, and especially for a sketch map of a part of the Alsek drainage basin.

³ This glacier was named after Capt. J. O'Connor, who crossed it in 1898 and furnished us with a sketch map of his route.

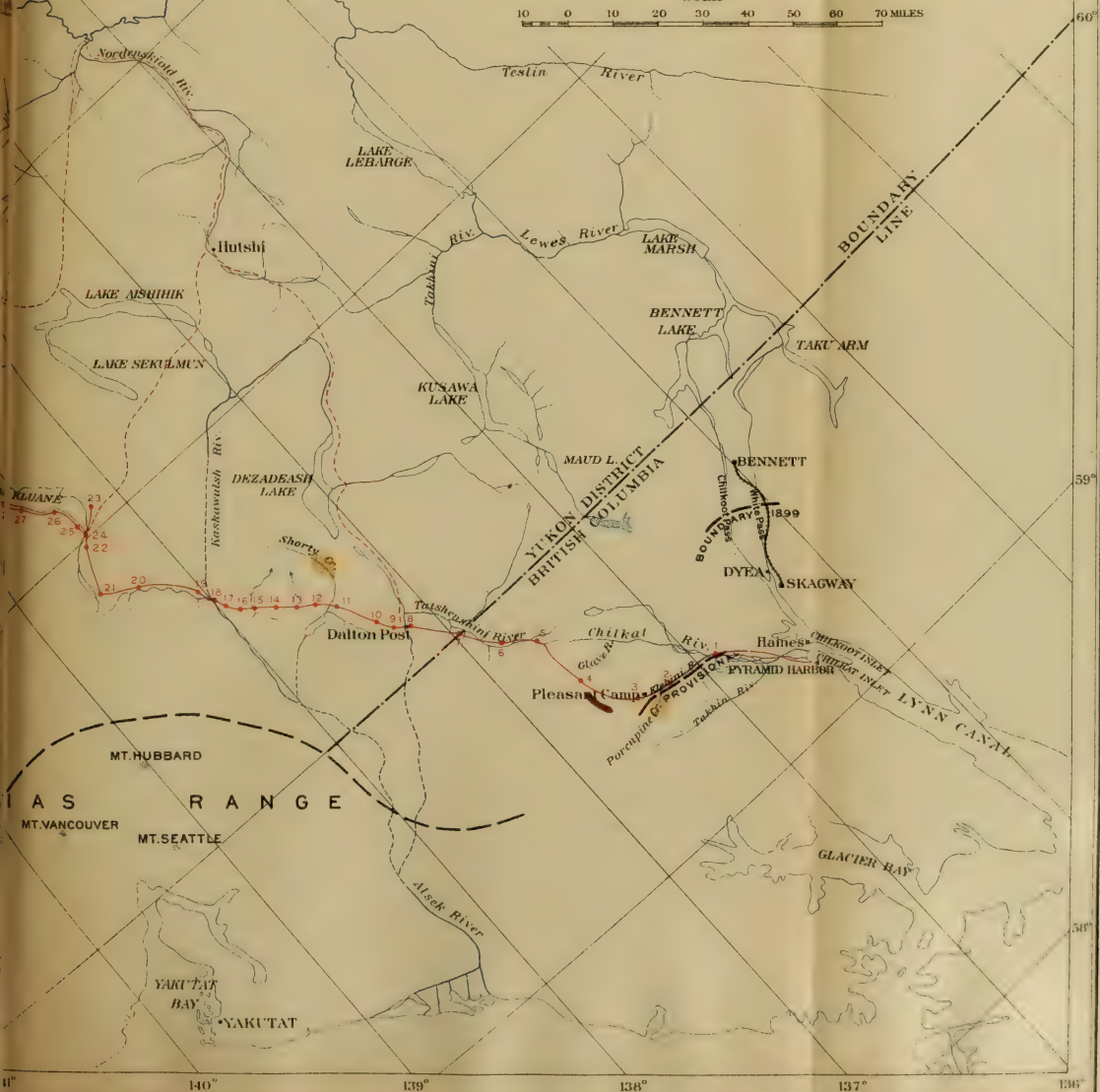
ROUTE FROM PYRAMID HARBOR TO EAGLE CITY AND LOCATION OF GOLD AND COPPER DEPOSITS AS FAR AS DETERMINED BY

ALFRED H. BROOKS

1899

Scale

10 0 10 20 30 40 50 60 70 MILES



us with the loss of our leader and a horse, who were swept downstream by the madly rushing current. We were much relieved when the entire expedition reached the west bank in safety.

On August 6 we reached the Klutlan Glacier, which we attempted to cross, but were forced to turn back because of the precarious footing which it offered our horses. The river below the glacier was almost as dangerous to cross as the Donjek, but we passed it in safety.

We remained near Kletsan Creek¹ two days to afford time for a hasty examination of the copper deposits, and on August 12 reached the White River. We followed the White nearly up to its glacial source, and then, turning westward, laid our course for a low divide, beyond which we hoped to find Tanana waters. We crossed this divide and on August 14 reached the glacier in which the Tanana River heads. Thence we made our way across a second divide to the Nabesna, a west fork of the Tanana. We followed the Nabesna downstream for about 20 miles, and then, taking a northwesterly course, reached the Tanana, near the mouth of the Tetling River, on September 1. On September 3, having built a boat and ferried our outfit and swum our horses across the Tanana, we continued our course in a northerly direction toward Fortymile River. After traversing the flat swamp- and lake-covered valley bottom for a few miles we reached the north wall of the valley, which rises by a gradual slope. The watershed lies close to the Tanana Valley, and to the north we followed a stream occupying a shallow valley. About 30 miles north of the Tanana this stream makes an abrupt turn to the east and probably flows into the White River. We continued on our northerly course and after crossing a second divide reached a broad valley which is tributary to Dennison Creek, a branch of the South Fork of Fortymile. We reached the South Fork of the Fortymile on September 10, and having renewed our supply of provisions,² which had run rather low, continued on by trail to the mouth of Steele Creek. Here a boat was procured and four of the party, including the topographer and the geologist, continued the journey to Eagle City by water, while the other two men brought the remaining 7 horses by trail. On September 16 the entire party assembled at Eagle City.

Our route was over 600 miles in length, and we made the journey in sixty-six days. Of this distance we were obliged to chop a trail for about 40 miles. We started with 15 good horses and 8 of them were left by the wayside, most of them being shot because they were too weak to keep up with the others.

¹ We there met E. J. Cooper and H. A. Hammond, who had come with a pack train from Copper River. Mr. Cooper gave us some valuable information about the region.

² In this connection we are indebted to Mr. Thomas Martin, of Napoleon Creek, who, true to the traditions of the Alaskan pioneers, received us hospitably and shared with us what provisions he had.

PREVIOUS EXPLORATIONS.

It is not my purpose to attempt a complete history of the previous explorations of the region traversed by our party. To give an account of the explorations and mapping of the southeastern part of Alaska would be almost to write a history of the explorations in the northern Pacific Ocean since the middle of the sixteenth century.¹

The head of Lynn Canal is said to have been first explored in 1796 by Shultz, an employee of the Russian-American Fur Company.² Since the purchase of the territory in 1867 the United States Coast and Geodetic Survey has steadily progressed in the mapping of the coast line and adjacent areas. The investigations of Professors Pratt and Davidson in connection with that Bureau have contributed much to our knowledge of this region. The reports and maps will be found in the publications and maps of the Coast Survey. In recent years the work of the International Boundary Survey has extended the mapping of the mountains adjacent to the coast of southeastern Alaska. The studies and explorations of Mr. John Muir, Profs. I. C. Russell, H. Fielding Reid, and G. Frederick Wright have added much to our knowledge of the glaciers of the Alaskan coast.

1877. Lieut. C. E. S. Wood,³ U. S. A., made a journey into the Mount Fairweather region with a party of native hunters, and was probably the first white man to see Glacier Bay.

1879. Prof. John Muir⁴ and Rev. S. Hall Young visited the Muir Glacier and explored Icy Bay. They were the first white men to explore Glacier Bay.

1872-1879. Arthur Harper made several prospecting trips into the White and Tanana river basins.⁵

1880. Captain Beardslee⁶ visited Glacier Bay in the steamer *Favorite*, and Ensign Hanus made rough surveys of the lower end of the bay.

1880. Mr. John Muir made a second visit to Glacier Bay.⁷

1882. Dr. Arthur Krause made explorations of Chilkoot and Chilkat passes.⁸

¹ Those interested in this matter are referred to *Alaska and Its Resources*, by William H. Dall; Bancroft's *History of Alaska*; and *Report of the Population, Industries, and Resources of Alaska*, by Ivan Petroff. For a bibliography of publications relating to Alaska, see *Pacific Coast Pilot*, Appendix 1, U. S. Coast and Geodetic Survey, 1879; William H. Dall and Marcus Baker.

² Dall, *op. cit.*, p. 317.

³ Among the Thlinkits: *The Century Magazine*, July, 1882.

⁴ The discovery of Glacier Bay, by John Muir: *The Century Magazine*, June, 1895.

⁵ A reconnaissance in the White and Tanana river basins: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 435 and 437.

⁶ Senate Ex. Doc. No. 105, second session, 46th Congress.

⁷ The discovery of Glacier Bay, by Eliza Ruhama Seidmore: *Nat. Geog. Mag.*, Vol. VII, April, 1896, p. 143.

⁸ *Deutsche Geographische Blätter*, Bd. V. Heft 4, 1882, with map. *Zeitschrift für Erdkunde*, Berlin, Bd. XVIII, 1883. Yukon district and British Columbia, by G. M. Dawson: *Geol. Surv. Canada*, 1887-88, p. 181 B.

1883. Lieut. Frederick Schwatka crossed the Chilkoot Pass and descended the Lewes and Yukon rivers, making surveys en route.¹

1885. Lieut. Henry T. Allen, U. S. A., with a small party, ascended the Copper River, crossed to the Tanana by the Suslota Pass, and floated down that river to its mouth.²

1886. Lieut. Frederick Schwatka, accompanied by Prof. William Libbey and Lieut. H. W. Seton-Karr, and two camp hands, made an attempt to ascend Mount St. Elias, and reached an elevation of 7,200 feet.³

1886. Prof. G. Frederick Wright⁴ devoted a month to the study of the Muir Glacier.

1888. W. H. and Edwin Topham, with George Broca and William Williams, ascended the southern slope of Mount St. Elias to a height of 11,460 feet.⁵

1888. William Ogilvie, Dominion land surveyor, made surveys from Dyea, on Lynn Canal, to the International Boundary, on the Yukon.⁶

1888. Dr. G. M. Dawson studied the geology of the Lewes River, Chilkoot Pass, and the head of Lynn Canal.⁷

1890. Prof. I. C. Russell, with Mark B. Kerr, topographer, and six camp hands, attempted the ascent of Mount St. Elias, under the joint auspices of the National Geographic Society and the U. S. Geological Survey.⁸

1890. Prof. H. F. Reid, with five companions, spent the summer in studying and mapping the region about Muir Glacier.⁹

1890. Messrs. S. J. Wells, E. J. Glave, and A. B. Schanz, on an expedition organized by Frank Leslie's Weekly, ascended the Chilkat River and, crossing the coast range, explored Lake Kusawa (then called Lake Arkell).¹⁰ There the party divided, and Schanz and Wells proceeded to the Yukon, while Glave, accompanied by Jack Dalton, crossed the divide to the Alsek waters and proceeded down that river to the coast.

¹Military reconnaissance in Alaska, 1883, with maps; second series: Senate Ex. Doc. No. 2, Forty-eighth Congress.

²A report on an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885. This report includes maps of three rivers, which up to 1898 were the basis of all maps of the region.

³Shores and Alps of Alaska, by H. W. Seton-Karr: New York Times, October 17, 1886. The expedition of the New York Times, by Frederick Schwatka: The Century Magazine, April, 1891, with sketch map.

⁴The Ice Age of North America, 1889, Chapter III.

⁵Scribner's Magazine, April, 1889; Alpine Journal, August, 1889.

⁶Klondike Official Guide, 1888.

⁷Ann. Rept. Geol. Surv. Canada, Vol. IV, 1888-89, Part B, with maps.

⁸Expedition to Mount St. Elias, by I. C. Russell: Nat. Geog. Mag., Vol. III, 1891-92, with maps.

⁹Studies of the Muir Glacier, by H. F. Reid: Nat. Geog. Mag., Vol. IV, 1892-93. Notes on the geology in the vicinity of the Muir Glacier, by H. P. Cushing: Nat. Geog. Mag., Vol. IV, 1892-93. Glacier Bay and its glaciers [with maps]. Sixteenth Ann. Rept. U. S. Geol. Survey, 1896, Pt. I, pp. 421-461.

¹⁰Report on the population and resources of Alaska, 1891, Eleventh Census, p. 9.

1890. Mr. S. J. Wells,¹ of the Frank Leslie Exploring Expedition, with one companion, crossed from Fortymile to the Tanana and continued down that river to its mouth.

1891. Prof. I. C. Russell, with a party of six men, made a second attempt to reach the summit of St. Elias, again under the auspices of the U. S. Geological Survey and the National Geographic Society.² At an elevation of 14,500 feet they were forced to turn back because of severe storms.

1891. Lieut. Frederick Schwatka, U. S. A., Dr. C. Willard Hayes, of the United States Geological Survey, and a prospector named Mark Russell, reached the head of White River by an overland route from Fort Selkirk.³ They crossed Skolai Pass and reached the coast by way of Copper River.

1891. E. J. Glave and Jack Dalton, with four pack horses, followed up the Chilkat River, crossed the two forks of the Alsek, and reached the upper end of Lake Kluane, then returned to the coast by the same route. They were the first to use pack horses in Alaskan explorations.⁴

1896. Jack Dalton,⁵ who accompanied E. J. Glave in 1890 and 1891, established a trail now known as the Dalton trail, from Pyramid Harbor to the mouth of the Nordenskiöld River. He had some years before established trading posts at Pleasant Camp on the Klehini, and at Dalton House on the Tatshenshini. He has made several trips into the White River country from Pyramid Harbor.

1896. J. E. Spurr,⁶ assisted by H. B. Goodrich and F. C. Schrader, studied the geology of the Yukon gold district, paying especial attention to the Fortymile and Birch Creek districts.

1897. Prince Luigi, with a strong, well-equipped party, succeeded in reaching the summit of Mount St. Elias.⁷

1897. J. J. McArthur made survey of Dalton trail, running from Pyramid Harbor to the mouth of Nordenskiöld River.⁸

¹ Report on the population and resources of Alaska: Eleventh Census, 1893. In a previous publication, *A reconnaissance in the White and Tanana River basins*: Twentieth Ann. Rept. U. S. Geol. Survey, I unfortunately omitted to mention this exploration of Mr. Wells.

² Second expedition to Mount St. Elias, by I. C. Russell: Thirteenth Ann. Rept. U. S. Geol. Survey, Part II [with maps].

³ An expedition through the Yukon district [with maps], by C. Willard Hayes: Nat. Geog. Mag., pp. 117-162, May 15, 1892.

⁴ Pioneer pack horses in Alaska, by E. J. Glave: The Century Magazine, Vol. XLIV, Nos. 5 and 6, September and October, 1892.

⁵ Mr. Dalton, of Pyramid Harbor, is the best informed man of the region, and we are much indebted to him for information furnished us.

⁶ Geology of the Yukon gold district, by Josiah Edward Spurr, with a chapter on the history and condition of the district, by Harold Beach Goodrich: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 87-392.

⁷ La Spedizione di S. A. R. il Duca degli Abruzzi al Monte Sant' Elia (Alaska), 1897; Ulrico Hoepli, Milano, 1900. The ascent of Mount St. Elias by H. R. H. Prince Luigi Amedeo: Archibald Constable and Co., Westminster, 1900. The ascent of Mount St. Elias: Sierra Club Bulletin, Vol. II, No. 3, Jan., 1898.

⁸ This survey is embodied in Dawson's map of portion of the Yukon district, Sheet III, corrected to January, 1898: Geol. Surv. Canada, 1888.

1898. J. B. Tyrrell studied the geology along the route of the Dalton trail. He also made explorations westward from Hutshi to the White River.¹

1898. Lieut. P. G. Lowe, U. S. A., with a pack train, went from Valdes to Fortymile post on the Yukon, by way of the Copper River. He crossed the Tanana near the mouth of the Tetling River.²

1898. Capt. W. R. Abercrombie ascended the Copper River to Mentasta Pass.³

1898. E. C. Barnard, United States Geological Survey, mapped the topography of the Fortymile quadrangle.⁴

1898. Russell L. Dunn visited the Dalton trail region and published some geological and mining notes.⁵

1898. W. J. Peters and Alfred H. Brooks, with a small party, ascended the White River and its tributary, the Snag River, in canoes, then portaged across to Tanana waters and followed the river of that name to its mouth. They made surveys along the entire route.⁶

1899. Oscar Rohm, employed by the United States Army as topographer, ascended the Chitina River with pack train to the foot of the Nizina Glacier. He then, with one companion, crossed by this glacier to the head of the Tanana, and continuing westward they crossed the divide to the Nabesna, and then returned to the coast by way of the Copper River.⁷

1897-1899. The Klondike excitement of these two years led to much exploration in this region by prospectors hunting for gold. Parties entered the region from almost every point of the compass. Some crossed the glaciers from Yakutat Bay to the Alsek, and ascended that stream, while some left the coast by way of Copper River and reached the White River by way of Skolai Pass. Others again came in from the Lewes River, and many along the well-worn Dalton trail. There are no authentic data relating to most of these parties. Here, as elsewhere in this northern region, in probably not a few cases, bleaching bones are the only records left to mankind of the indomitable will and unheralded heroism of the American prospector.

¹ Summary Report, 1888, Geol. Surv. Canada, pp. 36-46.

² A narrative of this expedition, together with a sketch map, is published in Reports of explorations in the Territory of Alaska, 1898; War Department, Adjutant-General's Office, No. XXV, July, 1899.

³ No surveys were made by this expedition, but a narrative is published in Reports of explorations in the Territory of Alaska, 1898; War Department, Adjutant-General's Office, No. XXV, July, 1899.

⁴ Explorations in Alaska in 1898, Map 10, p. 76; U. S. Geol. Survey, 1899.

⁵ The country of the Klondike: Mining and Scientific Press, San Francisco, Cal., 1898; Vol. LXXVII, Nos. 1998, 1999, 2000, Oct. 22-29, and Nov. 25.

⁶ The White River and Tanana expedition, by W. J. Peters and Alfred H. Brooks: Explorations in Alaska, 1897; U. S. Geol. Survey, 1899. A reconnaissance in the White and Tanana river basins in 1898, by Alfred H. Brooks: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, 1900.

⁷ An account of this expedition, with map, will be found elsewhere in this volume.

GEOGRAPHY.

The region on which our investigations throw more or less light is approximately blocked out by the Lynn Canal on the east, by the St. Elias Range on the south, by the 142d meridian on the west, and by the Yukon on the north (see Pls. XLI and XLII). It may roughly be regarded as a parallelogram along whose southern and western sides our route of travel lay and which lies for the most part within the Yukon Plateau belt.¹ While the investigations of 1899 were limited to a narrow zone along this route, yet a previous familiarity with the section from Lynn Canal across the Coast Range and down the Lewes to the Yukon, as well as previous studies along the Lower White and Tanana rivers, together with a liberal use of reports of the published work of others, will enable me to suggest some correlations which would hardly be warranted by the work of one season.

COAST LINE.

Lynn Canal, a deep indentation of the coast line, is one of the many tidal fiords which are so characteristic of the southeastern Alaskan coast and which indicate a drowned topography. Along the canal the steep slopes of the mountain rise precipitously, here and there interrupted by a bench marking a former level of depression.²

At the mouths of the larger rivers broad deltas have been built out into the fiord, and offer opportunities for settlements along a shore which is usually very precipitous. Such plains exist at the mouths of the Chilkat, Skagway, and Dyea rivers, and have been utilized for habitation. The upper part of Lynn Canal is divided by a narrow neck of land into two embayments, called Chilkoot and Chilkat inlets. The larger, containing Davidson Glacier, discharges into Lynn Canal near the mouth of Chilkoot Inlet, and the drainage of numerous other glaciers which do not reach tide water finds its way to Lynn Canal. The general aspect of the country near the canal is rugged and forbidding.

West of Lynn Canal is another fiord, Glacier Bay, one of the best known points in Alaska, annually visited by many tourists, who come to view its famous glaciers. Cross Sound connects these waters with the Pacific. West of Cross Sound, as far as Cape Suckling, which lies just east of Copper River, the cragged peaks of the St. Elias Range rise precipitously from near the coast and many glaciers clothe the mountain slopes, frequently fronting the sea. This stretch of the coast is remarkably even, its uniformity being broken only by Lituya Bay, Dry Bay at the mouth of Alsek, and by the larger indentation known as Yakutat Bay.

¹ A reconnaissance in the White and Tanana river basins, Alaska, 1898: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 425-494.

² At Pyramid Harbor benches were observed at about 100, 300, 400, and 700 feet above tide water.



A. PLEASANT CAMP AND JARVIS GLACIER FROM DALTON TRAIL.



B. UPPER TATSHENSHINI VALLEY, SHOWING BENCHES ALONG VALLEY SLOPE.

OROGRAPHIC FEATURES.¹

COAST RANGE.

North of Lynn Canal a chain of mountains, called the Coast Range, separates the Pacific and Yukon waters. Near Dyea the watershed is only about 20 miles from tide water. The range extends southeastward, close and parallel to the coast line, into British Columbia. Northwest of Chilkoot Pass the range trends inland, and finally loses its distinctive character and merges into the Yukon Plateau. Some mountains lying west of Lake Dezadeash, which have been called the Dalton² Range, possibly represent an extension of the Coast Range uplift. These mountains, as Dr. Hayes³ has shown, form a broad, elevated mass, having no dominant range. Near Lynn Canal, from an elevation of about 5,000 feet, the range is seen to be made up of innumerable peaks and minor ranges, whose crests rise to about the same elevation and show a remarkably even sky line. The Coast Range does not everywhere form the watershed between the Pacific and interior waters, for a number of rivers, such as the Stikine and the Taku, have their sources north of the Coast Range.

ST. ELIAS RANGE.

West of Lynn Canal, where the Coast Range passes inland, the St. Elias Range occupies the continental margin, and is a broad mountain chain stretching to the northwest of Cross Sound and Icy Strait (see Pl. XLII). To the southeast of these two straits, which lie nearly at right angles to the direction of its axes, the St. Elias Range is partially submerged, and is represented by the highlands of the Alexander Archipelago. Northwest of Cross Sound lies the Fairweather group of mountains, and still farther to the northwest the range increases in elevation, culminating in the peaks of St. Elias and Logan and probably others which have not been determined. To the northwest of these peaks the range, as Dr. Hayes⁴ has shown, bifurcates, and the most northerly of the two chains, called the Skolai Mountains on the accompanying maps, forms the watershed between the Chitina on the south and the Tanana and Nabesna rivers on the north, and also includes the Wrangell group of volcanoes. The southern chain approaches the coast and merges into the Chugach Range,⁵ on the Lower Copper River. The St. Elias Range proper has a length of about 300 miles and an extreme width of about 70 miles. From Cross

¹ See Pls. XLII and XLIII.

² Compare topographic map of Dalton trail, by J. J. McArthur.

³ Expedition through the Yukon district: *Nat. Geog. Mag.*, Vol. IV, p. 128.

⁴ *Op. cit.*, p. 129.

⁵ A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, 1898, by F. C. Schrader: *Twentieth Ann. Rept. U. S. Geol. Survey*, Pt. VII, pp. 341-423.

Sound to the Copper River it is a continuous mountain barrier except for the broad valley of the Alsek, which cuts completely across its axis. To the south of our route of travel from Lynn Canal to the White River we could see the bewildering mass of snow-clad mountain chains and peaks which make up this great range. The topography is craggy, and innumerable glaciers occupy the higher valleys, fed by extensive nevés.

NUTZOTIN MOUNTAINS.

In a previous report I have described the Nutzotin Mountains, from which the Nabesna and Tanana rivers emerge, and whence they debouch on the broad gravel plain of the Upper Tanana Valley. From the Nabesna these mountains have a southeasterly course and extend through to White River, but in the last 20 miles they decrease very much in elevation and become a low range of hills. The extension of the axis of this range to the southeast of the White would coincide with mountains to the north of Lake Kluane, which attain considerable altitude. These mountains, so far as we could observe, seem to constitute a more or less well-defined range as far as the Kaskawulsh River, beyond which they probably merge with the Yukon Plateau, though the mountains lying immediately north of the Chilkat River may belong to the same uplift. To the northwest of the Nabesna River this range is continued by what are called the Mentasta Mountains, which, in their northwesterly extension, join the great Alaskan Range. The extreme width of this chain is about 20 miles and its highest peaks measure 10,000 or 11,000 feet.

The above description of the Coast and St. Elias ranges and Nutzotin and Mentasta mountains includes all the mountain ranges proper embraced in the areas under discussion. Within the plateau belt to be described below mountains which rise above the general elevation of the plateau are not uncommon. In some cases a series of such mountains, arranged more or less linearly, suggests a synchronous uplift, but such mountains are usually separated by plateau areas, and can not be regarded as definite ranges. Mountains of this class are common between the Tanana and the Yukon. The Keechumstuk Hills¹ belong to this category.

YUKON PLATEAU.²

North from the Coast and St. Elias ranges stretches the great interior upland which has been called the Yukon Plateau.³ This is a dissected upland, whose remnants show an even sky line and mark a gently rolling plain, which slopes toward the northwest. In it the larger

¹ Often called the Razor-back Divide by prospectors.

² The relation of the plateau and the mountain ranges is shown in the profiles on Pl. XLVIII.

³ See Pl. XLIV, *A* and *B*, and Pl. XLV, *B*.



MOUNTAIN RANGES OF CENTRAL ALASKA

Topography by U.S. Geological Survey, U.S. Coast and Geodetic Survey, International Boundary Survey, and Geological Survey of Canada.

Scale $\frac{1}{3,600,000}$

0 10 20 30 40 50 Miles



ivers have cut broad valleys, the relief varying from 1,000 to 3,000 feet. This plateau has been traced from the region of the Upper Liard, in British Columbia, to the Lower Tanana, and thence to the big bend of the Yukon. In this distance it decreases in elevation from 5,000 or 6,000 feet in British Columbia to 2,500 feet near its north-western limit in Alaska. While in general the surface of the plateau slopes northwest there are irregularities in the plain marked by the plateau remnants, which, it has been suggested, may be due to warping.¹ The Yukon Plateau was first named by Dr. Hayes and has been described in more or less detail by various writers.²

DRAINAGE.

CHILKAT RIVER.

Of the three drainage basins which are in part included in this area that of the Chilkat River is the smallest. The river rises in a broad depression, which forms the divide between it and the Alsek River system. It has a southeasterly course, and in a distance of about 60 miles empties into Chilkat Inlet, an embayment of Lynn Canal.

In the upper part of its course the Chilkat River flows through a canyon or canyon-like valley which is incised in an older valley floor. The bottom of the older valley is marked by benches which extend from either side of the canyon to the base of the mountain slopes. About 10 miles above the Indian village of Klukwan the character of the Chilkat Valley changes. From this point to the coast the river is diversified into numerous channels and wanders over a broad gravel-filled valley bottom. This part of the valley probably represents a former inland extension of the tidal fiord, which has been filled with gravel and silt. The valley slopes rise abruptly, with an occasional bench, the highest one observed being about 1,000 feet above the water.

At its mouth the river has a broad delta which occupies the head of the inlet, and is gradually encroaching upon it. The delta is extended seaward by broad silt flats which are covered at high tide. The two most important tributaries are the Takhin and Klehini, both flowing from the west. The former joins the Chilkat 10 miles from the inlet, and the latter some 10 miles above. The Takhin rises in a glacier

¹A reconnaissance in the White and Tanana river basins, Alaska, in 1898: Twentieth Annual Rept. U. S. Geol. Survey, Pt. VII, p. 448.

²The Yukon district, by C. Willard Hayes: *Journal of School Geography*, Vol. I, No. 8, pp. 236-241. On the late physiographical geology of the Rocky Mountain region and Canada, with special references to the changes in elevation and to the history of the Glacial period, by Geo. M. Dawson: *Trans. Roy. Soc. Canada*, 1890, Vol. VIII. Report on an exploration in the Yukon and MacKenzie basins, Northwest Territory, by R. G. McConnell: *Ann. Rept. Nat. Hist. Survey of Canada*, Part D, Vol. IV, 1888-89. Geology of the Yukon gold district, by J. E. Spurr: *Eighteenth Ann. Rept. U. S. Geol. Survey*, Pt. III, pp. 259-260. The Yukon district, by Alfred H. Brooks: *Explorations in Alaska in 1898*; U. S. Geol. Survey, 1899, pp. 85-100. A reconnaissance in the White and Tanana river basins, Alaska, by Alfred H. Brooks: *Twentieth Ann. Rept. U. S. Geol. Survey*, Pt. VII, pp. 425-494.

which is part of the great snow and ice field north of Glacier Bay. The Klehini, up which our route lay, has its source in a broad, flat divide, similar in character to that at the source of the Chilkat. Up to Pleasant Camp the Klehini River occupies a gravel-floored valley, similar to that of the Lower Chilkat and showing similar benching. Above Pleasant Camp it flows through a narrow rock canyon which has been incised in an older valley floor.

An examination of the accompanying map (Pl. XLIII, in pocket at end of volume) will show that the headwaters of the Chilkat, Glave, and Klehini rivers are separated by very broad, flat divides. This broad depression, below which the rivers have cut sharp canyons, evidently marks an old water course which has been robbed of its drainage by the Chilkat and its tributaries.

The relief in this drainage basin is from 3,000 to 7,000 feet, and the divides stand at about 3,000. Small lakes are not uncommon, and so far as observed are the result of an interruption of the drainage by glacial action. The rivers of this system are all more or less glacier-fed streams and are, as a rule, turbid. They are swift flowing and, except for the lower course of the Chilkat, unnavigable. Their shifting channels and bowlder-covered bottoms usually make them difficult to ford.

ALSEK BASIN.

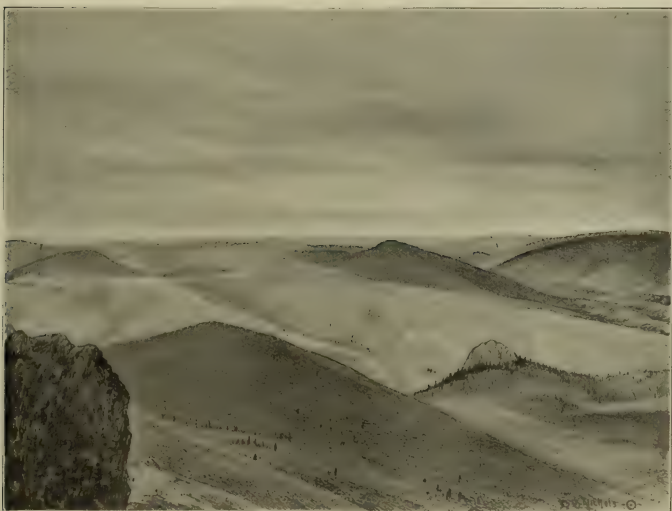
The Alsek River forks some 40 miles above its mouth. The eastern fork, called the Tatshenshini,¹ has its source, as has been described, near the head of the Chilkat. In its upper course it flows through a succession of rock canyons and broad gravel-filled valleys, the latter often containing silt and gravel terraces (see Pl. XLIV, *B*). Where the river occupies a canyon this has been incised in an old valley floor. Below Dalton House the river enters such a rock canyon but a few hundred yards wide and probably 100 or 200 feet deep. Above the canyon is a broad bench marking the old valley floor, which is several miles wide. Below this point the river has not been surveyed, and the only information available was obtained from prospectors. According to statements and sketch maps made by prospectors who are familiar with the Tatshenshini Valley, the river flows in a rock canyon 500 or 600 feet deep for most of the distance between Dalton House and its mouth. Above the canyon there is said to be a bench, sometimes several miles wide, which extends to the valley slope proper. This bench probably marks an old valley floor.

¹This nomenclature is in accordance with Canadian official maps. On the Yukon map, sheet 4, issued by the surveyor-general's office of Canada, March, 1898, the name Alsek is given to a river which is represented to have its source near Mount Logan, and which is shown to join the Kaskawulsh near the sixtieth degree of latitude. The best information obtained from prospectors would go to show that there is no river of such size coming in from the west, and that if it exists at all it must be an unimportant tributary. This being the case, the name Alsek would apply only to the lower river, below the junction of the Kaskawulsh and Tatshenshini.

For Alaskan names see pp. 487-500 of this report.



A. DISSECTED YUKON PLATEAU NEAR CAMP NO. 53; ELEVATION ABOUT 4,700 FEET; LOOKING NORTHWEST.



B. DISSECTED YUKON PLATEAU NEAR CAMP NO. 53; ELEVATION ABOUT 4,700 FEET; LOOKING NORTH.

The west fork of the Alsek, which is called the Kaskawulsh, has its source in a large, irregularly shaped lake, called Dezadeash, lying about 20 miles northwest of Dalton House. It leaves the lake with a northeasterly course, and in a distance of about 20 miles makes a sharp bend to the west, flowing in this direction for about 30 miles, when it turns to the southwest, and then keeps a general southerly course until it joins the Tatshenshini.

In its upper course the Kaskawulsh¹ flows through a broad, flat valley, and as far as our information goes it preserves this general character until it enters the mountains (see topographic and route map, Pl. XLIII, in pocket). Where crossed by the party the river valley has a basin-like character, is about a mile wide, and is bounded by low hills. It enters this basin through a constricted part of the valley and leaves it through a narrow rock canyon. The eastern valley slope rises by a series of small terraces up to 100 feet, and then extends inland for several miles as a broad, level bench. These terraces are undoubtedly of lacustrine origin, and the lake was drained by the cutting down of the canyon below the basin.

So far as known, the one large tributary of the Kaskawulsh is the river² draining the Aishihik Lake, which joins it near the point where it makes its southwesterly bend. The O'Connor River is another important tributary, which has its source in the O'Connor Glacier (see Pl. XLV, A); and this, in turn, has a tributary of considerable size, which rises in the direction of Mount Hubbard and joins the O'Connor near its mouth. This, like the O'Connor, is a turbid stream, and has a glacial source.

The Alsek River system includes a region of extremely varied topography. Its upper waters lie within the Yukon plateau, and here the valleys have been cut some 3,000 to 4,000 feet below the general level. The basin is drained by valleys which cut entirely through the St. Elias range, and here the relief must be many thousand feet, but accurate data are entirely lacking. The Alsek is said to be fed by numerous glaciers in that part of its course where it cuts the range. Waterfalls and rapids have been reported on both the lower Tatshenshini and the Kaskawulsh. The elevation of the Dalton House is about 2,500 feet, so that the Tatshenshini waters fall about that much in the distance of 100 miles to the sea. As would be expected from this fact, the reports state that the river is swift and turbulent. The maps show that the Alsek empties into Dry Bay, which reaches almost to the base of the mountains. This bay was thus named because its bottom is uncovered at low tide.

¹ See map by J. J. McArthur.

² This is sometimes called the Jarvis River by prospectors.

WHITE RIVER BASIN.

The White River has been heretofore described by me, in part from my own investigation, and in part from descriptions published by Dr. Hayes.¹ The following² is quoted for the sake of making the description of the geographic features complete:

The White River rises in the northern lobe of the Russell Glacier, which comes down from the St. Elias Mountains and flows east for about 40 miles nearly parallel with the range, and receives from it numerous tributaries. In its upper course it has a broad, gravel-floored valley some 10 miles in width, which gradually narrows down and assumes a canyon-like character. The narrow valley continues for a distance of 20 miles, and then the river debouches on a broad valley lowland. This second basin has a length of over 75 miles and an extreme width of 50 miles, while its floor is also composed of river gravels. It embraces not only the White River Valley and some of the confluent streams, but is extended through to the Tanana by broad, flat valleys, while to the east it is continued by the valley of the Nisling River. Here and there the comparatively even plain of the lowland is interrupted by knobs, hills, and mountainous masses, which rise rather abruptly. . . .

Some 10 miles below the mouth of Snag River the flats end abruptly and the White enters a narrower valley. In this part of its course the valley bottom is some 1,300 feet below the plateau surface. Terraces are found on both sides as far as the mouth of the Klotassin, below which they are replaced by steep granite bluffs. The Klotassin, which at its mouth is some hundred yards wide, is a clear-water stream flowing in a broad, flat-bottomed valley. Between the Klotassin and the Katrina rivers the White River Valley is rather contracted, with abruptly rising walls, while below the Katrina it gradually widens out and continues in this form to its junction with the Yukon. The valleys of both the Katrina River and La Luc Creek are broad and flat, and they are both clear-water streams. At the junction with the White the Yukon makes a right-angled bend to the northeast, so that the axis of the White River Valley is extended by the Yukon below its mouth. On the Yukon, opposite the mouth of the White, steep bluffs rise rather abruptly some 1,400 feet above the river. The junction of the two rivers is in British Northwest Territory, some hundred miles above Dawson, and the total length of the White is about 200 miles.

Throughout its course the White is a turbid, swiftly flowing stream, and it is shallow, with numerous channels, and is studded with constantly shifting sand bars and islands. It has all of the characteristics of an overloaded stream. No current determinations were made on the White River, but rough estimates show currents of from 5 to 10 miles an hour.

In the above the confluent streams of the Lower White, which are comparatively small, are described, but those of the upper river, with which I was not then familiar, are omitted. The largest tributary of the White is the Donjek, which rises in a large glacier fed by the ice-covered St. Elias Range, and, flowing in a northwesterly direction, joins the White some 60 miles below its source. For the first 20 miles the Donjek has a broad, gravel-filled valley; then, turning northward, it enters a canyon. This canyon is not many miles in extent, and where the Kluane joins the Donjek the valley broadens out again. The Kluane has one of its sources in Lake Kluane, which it leaves through a canyon-like valley. Lake Kluane is about 50 miles long,

¹ An expedition into the Yukon Basin; *Nat. Geog. Mag.*, Vol. IV.

² *Twentieth Ann. Rept. U. S. Geol. Survey*, Pt. VII, pp. 48-49.



A. O'CONNOR GLACIER FROM SLIMS RIVER VALLEY



B. MOSS-COVERED PLATEAU IN FOREGROUND, MOUNT NATAZHAT IN DISTANCE.

and occupies a part of a former valley which extended from Lake Dezadeash to the White, crossing the Donjek and joining the flat of the Middle White by the Koidern Valley. Creadon River, joining the Kluane from the east, occupies a part of this former drainage channel. Another tributary is Slims River, which has its source in the O'Connor Glacier (see Pl. XLV, A). The volume of the Donjek is probably equal to that of the main White River.

The Koidern, which occupies a part of the old valley described above, is a comparatively small river. The Klutlan, which joins the White above the canyon, is fed by the large glacier of that name, and, considering its length, has a large volume of water.

TANANA BASIN.

The Tanana River rises south of the Nutzotin Mountains in a glacier of the same name. Near its head it is joined by two tributaries, nearly equal to it in size and also having glacial sources. These headwaters lie in a broad basin having an elevation of about 5,000 feet, which is connected with the White River waters by a broad gap about 1,000 feet in elevation. The gap between the Tanana and Nabesna rivers is narrower, but has about the same elevation.

Below this basin the Tanana, flowing northeastward, enters the Nutzotin Mountains, and here its valley is constricted for a distance of about 20 miles. It then debouches on the broad valley lowland of the Upper Tanana, here about 25 miles wide. It flows across this plain until it reaches the north wall of the valley, and then turns abruptly to the northwest.

The Nabesna is the largest tributary of the Tanana. It has a glacial source on the northern slope of the Mount Wrangell group, flows in a northeasterly and northerly direction, and joins the Tanana near the western margin of the Upper Tanana Basin. Throughout its course, as far as known, the Nabesna¹ flows in a broad valley, and is probably much older than the gorge of the Tanana. Both the Tanana and Nabesna are swift-flowing streams until they reach the valley lowland already referred to.

I quote the following from the report on the Tanana:²

The broad lowland ends near the mouth of the Tetling, where the valley is contracted to about 7 miles. West of Mount Chisana the Tanana Valley is formed by a series of connecting basins, possessing outlines of parallelograms. These will be described below, and their origin ascribed to structural lines. This basin-like character is more or less well marked to about the mouth of the Silok River, where the recession of the south wall of the valley produces another lowland, some 30 miles wide, and which continues to broaden out to the west. Something of the same basin-like character is preserved in this part of the valley by the succession of reentrant angles in the northern escarpment.

¹ The headwaters of the Nabesna have not been explored above the point where our route crosses the river.

² Twentieth Ann. Rept. U. S. Geol. Survey, Pl. VII, pp. 450 and 451.

Where the Tanana leaves the mountains, near its headwaters, the peaks on either side of the gorge rise over 4,000 feet above the river level. The summit of Mount Chisana, a part of the old plateau surface, is some 1,500 feet above the river, and the top of the escarpments which form the southern valley wall of the Middle Tanana are believed to have about the same amount of relief, though the elevations were unfortunately not determined and the contouring on the accompanying topographic map was made purely from estimated elevations. The ridges which bound the Tanana on the north near its mouth stand not over 300 or 400 feet above the water.

The northern tributaries of the Tanana are all sluggish streams, flowing in broad valleys, and have considerable depth. They are as a rule clear or only slightly turbid, carry little sediment, and have no deltas at their mouths. The southern tributaries, having their sources in the high mountains, are all shallow, turbid, swift-flowing streams, usually with large deltas. The formation of these deltas is probably the chief cause for the position of the Tanana River close to the north wall of its valley, though this may have been aided by warping.

The Nabesna River is the most important tributary of the Upper Tanana and nearly equals it in size. Like the Tanana it leaves the mountains through a narrow valley, and on reaching the lowland continues its course to the northeast until it joins the main river. The Tetling is a river of secondary importance, draining a group of small lakes which lie within the valley. These lakes probably owe their origin to the damming of the former course of the Tetling by the delta deposits of the Nabesna. Its old course is marked by a series of small lakes which may be seen on the topographic map. The Tok River is of comparatively small size and in its character is the exception among the rivers from the south. Rising as it does in the depression between the Nutzotin and Alaskan mountains, it is not fed to any extent by glacial streams or streams from the snow mountains, and therefore has clear water. The Robertson and Johnson rivers are both swiftly flowing, shallow, turbid streams, and the waters have a slightly greenish tinge. These rivers leave the mountains through narrow valleys, and both have broad deltas and glacial sand bluffs at their mouths. The Goodpaster and Volkmar rivers flow in broad valleys and are sluggish streams. The Volkmar is said to have its source in a rather rugged mountain region. The Delta River is much like the Robertson and Johnson in its general character, except that its valley is somewhat broader. The Mahutzu and Silok rivers are similar in character to the Delta, but are considerably smaller.

The Salchaket and Chena rivers were not visited by our party, but both have broad, flat valleys. The Nilkoka River and Baker Creek have the characteristics of the other rivers of the north side of the valley. The Cantwell has turbid waters and many sand bars, but in its long journey across the valley it has lost something of its swift character. The Toklat is a deep, muddy stream, and in its lower course has a comparatively moderate current. It has never been explored, so of its upper course we have no information.

From where the Tanana leaves the mountains until it reaches the north side of the broad valley at its first great bend it is a shallow, swift-flowing stream, comparable in every way to the White River. Below this point to the contraction of the valley, near where the Fortymile trail reaches it, the Tanana has a very slow current and a very tortuous course; in many places it consists of little but a chain of ox-bow lakes. A few short riffles occur in this part of the river, but usually the current does not exceed 2 or 3 miles in all. Below this sluggish part of the Tanana to a point about 10 miles above the Cantwell River the current is usually very swift. Several rapids are marked on the map, none of which, however, are due to rock barriers. In the region of Bates Rapids the river has spread out until it is several miles in width and has innumerable channels, sand bars, and islands. Below the Cantwell River to the mouth of the Tanana it is usually confined to one or two channels and has a current of from 3 to 5 miles an hour.

FORTYMILE RIVER.¹

This river is tributary to the Yukon, which it joins in British Northwest Territory about 30 miles above the international boundary. The drainage basin of Fortymile lies entirely within the Yukon Plateau, and its headwaters reach far southward close to the Tanana Valley. About 60 miles from its mouth the Fortymile forks, the southerly branch and its tributaries heading near the Tanana and tributaries of the White. The north fork has a general east-and-west course and heads opposite the Volkmar and Goodpaster rivers, which flow into the Middle Tanana. The north fork has been but little explored, and its location on the accompanying maps is only approximate. It is said to flow through broad, shallow valleys. The basin of the south fork has been fairly well explored, and its creeks flow in broad, shallow valleys, the relief being from 800 to 1,500 feet. Fortymile Creek itself has a well-marked bench some 400 feet above the present water level, which Goodrich has shown to be an old valley floor.² Below this bench the river flows through a narrow canyon for much of its course. It leaves this canyon about 20 miles from the Yukon, and from there on has a broad valley. In this lower course it has but a sluggish current, while above swift water is frequent and rapids are not uncommon.

The broad, shallow valleys at the headwaters of this stream are probably synchronous in origin with the old valley floor of the Lower Fortymile. While the basin lies entirely within the Yukon Plateau and the even upland surface is a very marked feature of the topography, yet a number of isolated mountains and mountain masses rise above the plateau surface. Examples of these are Fortymile Dome, Glacier Mountain, and Sixtymile Butte.

PHYSIOGRAPHIC NOTES.

In a previous report³ I have attempted a brief summary of the physiographic development of the White River and Tanana River basins. The area now under discussion belongs to the same physiographic province, and hence the history of the development of its topographic forms is similar. The investigations of the past season (1899) throw much light on some of the problems, but as yet the notes have not been worked up in detail. In studying this area the physiographer is still hampered by the lack of sufficient topographic data and by the fact that even where contoured maps are available the elevations given

¹ See Pl. XLIII.

² *Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, Pl. 111, 1886-1897, p. 276.*

³ *Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 452-460.*

are only approximate, they having been determined very largely by aneroid barometer.

The Yukon Plateau, already described, is a peneplain which was formed probably in Middle Tertiary times. It slopes gently to the north and west, but has some undulations which have been ascribed to deformation. Unreduced areas or monadnocks rise above the peneplain, in some cases to the height of 1,500 feet or more. The ranges lying to the south of the plateau are rugged, with sharp outlines, and are comparatively young topographic forms. Some broad gaps which are found in these ranges, such as Mentasta Pass and some depressions at the head of the Cantwell, are believed to have been formed at the same time as the peneplain. Subsequent to the planation an orographic movement took place and the area was elevated far above its present position, and during this cycle the rivers carved deep, broad valleys. A depression followed which brought the plain nearly to its present position, and the rivers began building up their flood plains. Another elevation revived the activity of the streams, and they incised their channels in their former flood plains, whose remnants are now seen as terraces and bluffs.

In the previous discussion of the development of the present drainage system it was shown that the great gravel-filled basin of the Middle White and Tanana represents a part of an old river valley which formerly drained eastward, and which was called the White-Tanana. It was also shown that the constricted portion of the Tanana Valley is a comparatively new cutting, and that in this part of the river a divide existed between this lower part of the Tanana and the river described above, which occupied parts of the Upper White and Tanana valleys. The Lower White, probably having its source in Ladue or Katrina rivers, was also a distinct river from the old White-Tanana.

The work of the past season enabled me to trace the former water course of the White-Tanana eastward. It leaves the Middle White River Basin by the present valley of the Koidern (see Pl. XLVI, *A* and *B*), then, crossing the Donjek, finds its way by a broad, flat divide to Lake Kluane. From the eastern end of this lake the broad, flat valley of the Creadon River continues the old water course, probably reaching Lake Dezadeash by way of the Schwack Valley. From Lake Dezadeash the old river turned southward across the flat divide which separates the lake from the Tatshenshini waters. From this point on I have no personal knowledge of this old waterway, but the best evidence available indicates that it found its way to the sea by the Tatshenshini¹ and Alsek valleys. The Alsek is probably an antecedent river which maintained its position during the St. Elias uplift.

¹ From the former discussion of this old drainage channel it was suggested that it might have reached the sea by way of Lynn Canal. The studies of the past summer proved that this supposition was erroneous as the gaps on the divide between the Chilkat and Alsek basins are too high to admit of such an outlet.



A. VIEW LOOKING NORTHWEST ACROSS THE DONJEK DOWN THE VALLEY OF THE KOIDERN RIVER, SHOWING LOW DIVIDE BETWEEN THE KOIDERN AND THE DONJEK.



B. LOOKING ACROSS THE DONJEK, SHOWING CANYON ON THE RIGHT.

The basin of the Upper White during this time drained through a broad valley now occupied by a small stream and lake and running almost due eastward from the front of the Klutlan Glacier. This stream joined the main water course near the head of Koidern River. The accompanying sketch (fig. 21) shows the position of this old water course. The fact that the divides marking this old drainage system have small relief compared to the present waterways goes to show that this change in drainage has been very recent. Our present facts do not warrant a definite statement as to the cause of this change in the river system. I would call attention, however, to the fact that a northwesterly tilting, corresponding to the present inclination of

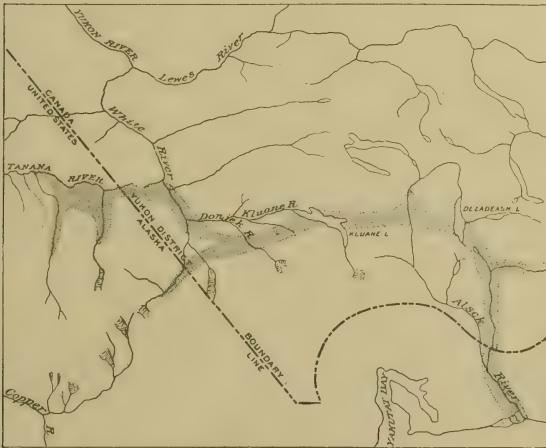


FIG. 21.—Sketch map showing former drainage channel.

the plateau, would give the northward- and westward-flowing streams the advantage in rapidity of cutting, which would be quite sufficient to cause this change in drainage. The position of the ice front may have been the cause of the change. Where the Cordilleran Glacier reached its maximum extension the southward-flowing streams would be ice dammed, while the drainage to the north would be unimpeded.

Among the striking features of the topography are the broad, flat east-and-west valleys. The series of broad depressions which mark the old drainage channel of the Tanana-White have already been referred to, and there are several others running parallel to these. As examples we have the valleys of the Nisling, the Klotassin, and the East Fork of the Kluane. A similar depression is said to connect

the lower end of Aishihik Lake with the upper end of Lake Kluane. Another connects the valley of Kashaw River with Lake Dezadeash. In each case the size of the present stream is entirely disproportionate to the size of the valley. The drainage of many of these old valleys is taken by rivers flowing directly across them and leaving them by narrow canyons. The Upper White, the Donjek, and the river draining Lake Kluane flow northward across broad valleys and thence through narrow canyons. The broad depressions must be classed as consequent, the canyons as subsequent, drainage. Pl. XLVI, *A*, is a view looking westward across the Donjek and showing the consequent valley, which is parallel to the strike. Pl. XLVI, *B*, shows the subsequent drainage through the canyon of the Donjek.

The unadjusted drainage conditions are well illustrated by the Kashaw River. Shorty Creek, which is the name given to the upper part of this river, leaves the mountains through a narrow gorge and debouches on a broad alluvial fan in the Kashaw Valley. Though but a few miles from Lake Dezadeash, and separated from it by a very low divide, Kashaw River flows southward, away from the lake. It is stated on good authority that Shorty Creek sometimes flows southward, sometimes northward, depending on what part of its alluvial fan it is occupying. An examination of the topographic map (Pl. XLIII) will show that this diversity of drainage involves a circuit of a hundred miles or more.

GEOLOGY.¹

GNEISSIC SERIES.

The oldest rocks of the region, so far as determined, are a complex of gneisses with various basic and acid intrusives. The gneisses, with which are associated crystalline schists, are intricately folded and often much sheared. In general, they are of an acid character, but basic schists are also present. The associated igneous rocks can be divided into two classes, namely, those that were intruded previous to the major deformation, which are much sheared, and the later intrusives, which are comparatively massive. They include several varieties of granite with some dioritic and gabbroic rocks. If the relative amount of deformation be used as a criterion, the basic rocks are the older, the younger intrusives being of an acid character. The latest intrusive rock is a white granite, often aplitic, which is found massive in dikes throughout the series.

The gneissic complex is well exposed on the Lower White, where it was studied by me in a previous season. The investigations of the past season (1899) have added but few facts relating to this group of rocks, for in the region north of the Tanana, where the main gneissic belt was crossed, there were very few exposures. A somewhat more detailed

¹ See Pls. XLVII and XLVIII.





135°

134°

133°

132°

131°

GEOLOGICAL RECONNAISSANCE MAP

OF
ALASKA, BRITISH YUKON DISTRICT, AND BRITISH COLUMBIA

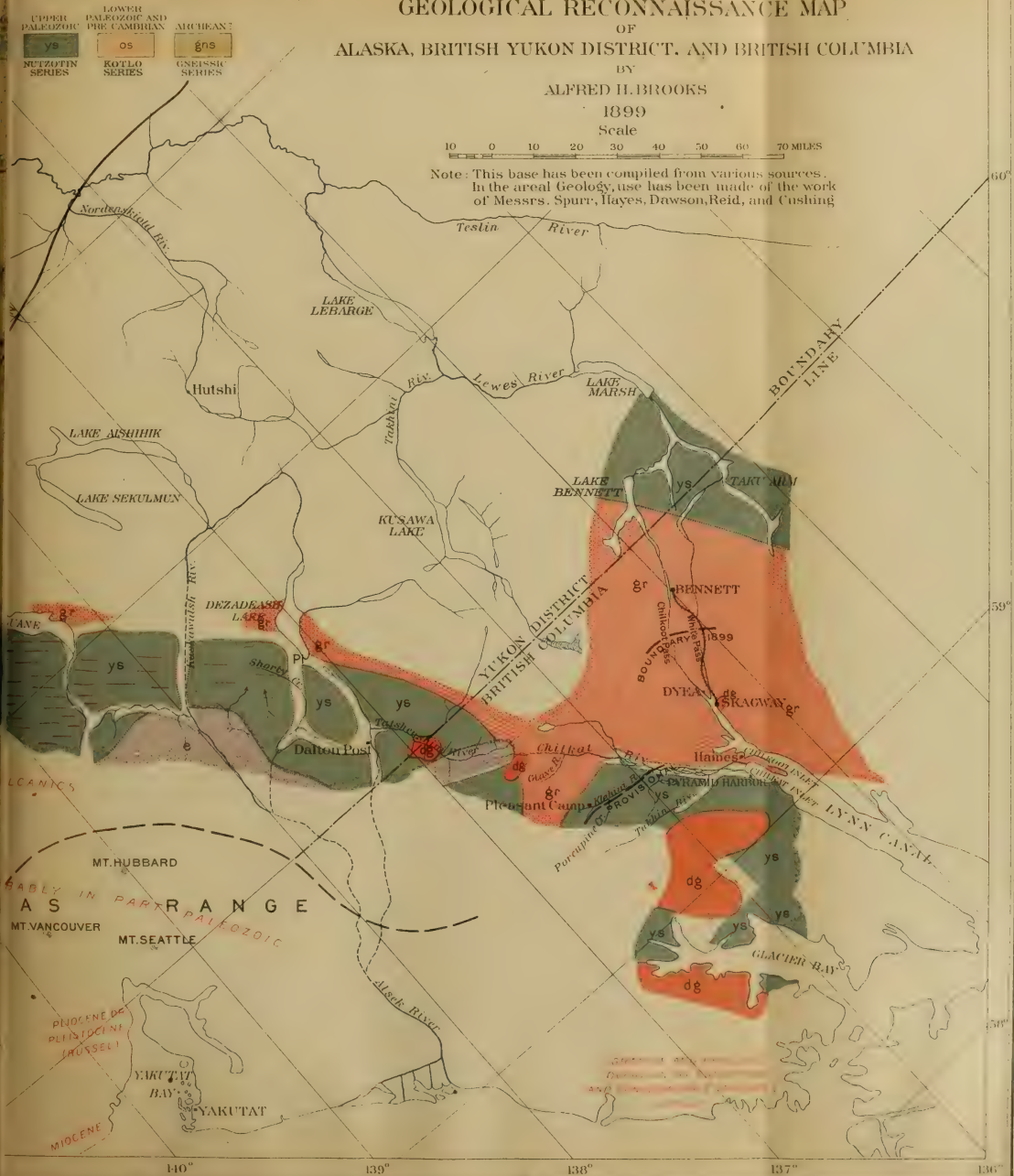
BY
ALFRED H. BROOKS

1899

Scale

10 0 10 20 30 40 50 60 70 MILES

Note: This base has been compiled from various sources.
In the areal Geology, use has been made of the work
of Messrs. Spurr, Hayes, Dawson, Reid, and Cushing



60°

59°

58°

140°

139°

138°

137°

136°

description of the various rock types found with the gneisses is given in the report already cited.

The gneisses are classed as Archean because they are apparently older than all of the sedimentary rocks. The sedimentary series are believed to overlie the gneisses unconformably. On the accompanying geological map (Pl. XLVII) the gneissic series is shown to occupy a broad belt lying between the Yukon and the Tanana and extending eastward across the White. The extension of the gneisses east of the White is made on the bases of some notes furnished me by Dr. Hayes.¹ To the north the continuity of the gneisses is interrupted by two belts of the older sedimentary series, which are infolded with them. According to the best information these belts of sediments do not extend far to the west, and are so represented on the map.

The general strike of the gneisses is northwest and southeast. The dip of the foliation is usually low and variable, though prevalently to the southeast. The series is entirely crystalline and includes no rocks, so far as known, of sedimentary origin. The cross jointing of the series has been previously described,² and the variation in direction of the jointing and its consequent effect on the topography has been ascribed to two synchronous thrusts coming from different directions.

KOTLO SERIES.³

Mr. Spurr, in his account of the geology of the Yukon district, describes three series of sediments, which he names the Birch Creek, Fortymile, and Rampart series. He shows that the first two are conformable and are overlain unconformably by the Rampart rocks. In my previous report on this region I describe two groups of rocks—the Nasina series and the Tanana schists. These were believed to be the equivalents of the rocks described by Spurr, but as no definite correlation could be made I was forced to use a new nomenclature. The western extension of the Tanana schists was recognized by Mr. W. C. Mendenhall,⁴ and he applied the same name to them.

On the accompanying map all these older sedimentary rocks have been grouped together under the name "Kotlo series." I have thus grouped together under this heading a number of different formations, probably including vast thicknesses of strata, but will make no attempt here to describe them in detail. For special descriptions see the reports already cited.⁵

¹ I am much indebted to Dr. Hayes for the use of his geological notes, made on the trip which has already been referred to.

² Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 464-465, 481-482.

³ On the plate showing profiles and known geology (Pl. XLVIII) these rocks are termed the Older Sedimentary series.

⁴ A reconnaissance from Resurrection Bay to the Tanana River, Alaska, in 1898; Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 265-340.

⁵ In a recent publication Mr. R. G. McConnell has described the rocks of the Klondike region and has grouped them in four different formations, having given to each a new name. These formations are probably equivalent to some of the rocks studied by Spurr and myself in the Fortymile region, and would therefore be included in the older sedimentary (Kotlo) series. See Preliminary report on the Klondike gold fields: Geol. Surv. Canada, 1900, No. 687.

This series is of especial interest, because it probably embraces all the gold-bearing rocks of the Upper Yukon. The rocks have only this one character in common, and are far from being a stratigraphic unit. The age of these older sediments has not been established. Mr. Spurr, in his studies of the Rampart rocks, believes them to be probably Silurian. The only paleontological evidence is a single shark's tooth. As far as known to the writer, no other fossil has ever been found in them. If the Rampart series are pre-Silurian, the Birch Creek, Fortymile, Nasina series, and Tanana schists are probably lower Paleozoic or pre-Cambrian.

These rocks have a general parallelism in strike to the gneisses, and their dips are very variable. In general the dips are low, the type structure being an open fold. The rocks of the older series in this subdivision are considerably metamorphosed, being often quite crystalline. The lowest beds of this group are quartz-schists, frequently containing some clastic crystalline material (Birch Creek series and Tanana schists). These quartz-schists become calcareous upward and are succeeded by a vast thickness of limestone, which is usually crystalline (Fortymile series, Nasina series). Above the limestones an unconformity occurs, and above this effusive rocks of vast thickness are found (Rampart series). The beds below this unconformity show evidence of having suffered much more deformation than those above. Throughout the older sediments acid and basic intrusives are not uncommon.

GREENSTONE-SCHISTS.

The greenstone-schists shown on the geological map in the White and Tanana River valleys are chiefly of a gabbroic and dioritic character, with numerous schists made up largely of secondary minerals, such as chlorites, actinolite, zoisite, and epidote. Among them are some finely banded rocks which, when studied under the microscope, were found to be tuffaceous. The investigations of 1898 showed these rocks to be largely intrusive and to be younger than the Tanana schists, which are here included in the Kotlo series.¹ These rocks are differentiated from the gabbroic and dioritic rocks, to be described below, because they are far more schistose. These greenstone-schists seem to be more closely related to those found associated with the gneisses than to any other intrusives of the region. They were in a previous report correlated with Spurr's Rampart series, but this correlation, on further study, seems doubtful, and they are therefore mapped as a distinct series.

¹ A reconnaissance in the White and Tanana river basins: Twentieth Ann. Rept. U.S. Geol. Survey, Pt. VII, p. 470.

NUTZOTIN SERIES.¹

Along our route of travel from Pyramid Harbor to the Nabesna River were exposed slates, white limestones, and flags, with some sandstones. These rocks are rather closely folded and strike in a north-west-southeast direction. From the general facts of their distribution and the relative amount of deformation it is believed that they are younger and that they overlie the older sediments unconformably. Future work will undoubtedly resolve the rocks of this series into many different horizons, but for the present purpose it has been thought best to group them together. Professors Reid and Cushing in their work around Glacier Bay² found a series of white limestones and argillites. In the former they found fossils of Carboniferous age. These rocks of Glacier Bay have been included with the younger sediments, both on lithological similarity and paleontological evidence.

In the upper basin of the White River, on Kletsan Creek, are exposures of a white limestone which carries many fossils. Many of the fossils collected from this point were unfortunately lost, but a few which were submitted to Mr. Charles Schuchert, of the United States National Museum were determined to be of Carboniferous age. I make the following extract from Mr. Schuchert's report on these fossils:

Kletsan Creek ("9 AB 171"):

<i>Productus cora</i>	} White crystalline limestone.
<i>Productus</i> , 2 undet. species..	
<i>Seminula</i> , 1 undet. species..	
<i>Stenopora</i> , 1 undet. species..	

Pebble from Kletsan Creek ("9 AB 150"):

Fusulina (not the common American species, *F. cylindrica*).

These two localities are of one general horizon in the Upper Carboniferous, which seem to be the same zone as that near Circle City discovered by Mr. Spurr (Takandit series) or a closely related one. I have made no specific determinations, since the fauna is not to be correlated with that of the Upper Carboniferous of the Mississippi Valley, but with the *Fusulina* zone of China, India, and the eastern slopes of the Urals.

This belt of limestone was traced from near the Kashaw River to the Nabesna with more or less interruption. Immediately underlying the white limestone are series of slates or argillites, possibly the same as those on Glacier Bay, already referred to.

In the report cited I have described what I have called the Wellesley formation, which consists of heavy conglomerate beds associated with black slates. The few fossils which were collected from these slates show that the formation is of either Devonian or Carboniferous age, and this area, therefore, is included with the younger sedimentary series.

¹ On the plate showing profiles and known geology (Pl. XLVIII) these rocks are termed the Younger Sedimentary series.

² See footnote 9 on p. 341.

On the above rather fragmentary evidence a belt of rocks running parallel to the St. Elias Range at its northern margin has been indicated on the accompanying map and provisionally named the Nutzotin series. This belt is interrupted by the younger effusive rocks and by the Pleistocene deposits of the larger valleys.

Like that of the rocks of the region, the strike of this series is about northwest and southeast. The dips are variable, but more often to the south than to the north. The type of structure is rather of closed folds, sometimes plainly overturned to the north. The deformation resembles the Appalachian structure and differs very materially from the open-fold type of the older rocks lying to the north.

If the interpretation is correct, the oldest bed of this series is the heavy conglomerate, included in a previous report in the Wellesley formation, on the Upper White and Tanana. This is succeeded by black slates, often much crumpled, and becoming more calcareous toward the top. Then there is a great thickness of slates, graywackes, and impure limestones, in ascending order, intruded by many basic dikes and containing probably some effusive igneous rocks and tuffs.

This part of the series was well exposed on the Nabesna River, along our route of travel. It here contains much igneous material and somewhat resembles Spurr's Rampart series of the Fortymile basin, but for structural reasons, as well as because of its areal distribution, it is correlated with the younger clastic series—the Nutzotin series. Deposits believed to be the equivalent of these beds, exposed on the Nabesna and Lynn Canal, contain little, if any, igneous material. The youngest beds of the series is the limestone, usually crystalline, in which, as has been stated, fossils have been found.

When the region is studied in detail this series will undoubtedly receive many subdivisions, for as mapped it must include beds aggregating many thousand feet in thickness. It is quite probable, also, that in this hasty reconnaissance some older beds have been included in this younger series.

At several localities igneous rocks which are plainly effusive rocks were found associated with this series. These effusives are quite distinct from those regarded as Tertiary and Pleistocene and are probably much older. No areas of these older effusives were found large enough to represent on the accompanying geological map. With them were found some tuffs and conglomerates, the pebbles of the latter being made up of effusive material. Such rocks were noted along the southern margin of Lake Kluane.

INTRUSIVES.

The intrusive rocks of the region have been differentiated into two classes on the accompanying map—those of a granitic type and those of dioritic and gabbroic types. The former are by far the most

extensive. The largest area of granite is that of the Coast Range, which has been traced by Dr. Dawson, Dr. Hayes, and others from British Columbia to the Chilkoot Pass. Typically this is a hornblende- or biotite-granite, usually more or less uniform. I found a granite of this character near Rainy Hollow and again near the eastern end of Lake Kluane; also on the Nabesna. Near the Kluane Valley Dr. Hayes crossed a similar belt of granite, which is represented on the accompanying map. Granite has also been reported both southeast and northwest of Dezadeash. The distribution of these areas suggests that they all belong to the same intrusive mass, which was injected along an axis running northwest and southeast. It is quite possible that future work will trace a continuous body of granite throughout this belt. In the work of the past summer the granite was found to be massive, but to have well-developed joint planes.

In studying the section from Skagway across the White Pass shear zones were found in the granite, along which it had been altered to a finely foliated schist. These shear zones are of very small extent and are probably lines of faulting. At Skagway and at other points along this route the granite is found to be cut by dikes of dioritic and diabasic character. About 5 miles west of Skagway a large mass of porphyritic rocks was observed, which is probably effusive. The talus slopes and stream gravels at other points along this route indicate that there are other considerable masses of effusive rocks at various localities within the area of the Coast Range granite. At the upper end of Lake Kluane dioritic and diabasic dikes were found cutting the granite, and also syenitic rocks. Coarse pegmatites have there also an extensive development. On the Middle and Lower Tanana hornblende-granites of a similar type were found associated with the gneisses and mica-schists, which are classed as Archean. These granites lie on the extension of the same axis of intrusion. Similar areas of granite entirely distinct from those on this axis were found in various parts of the region, but most of them are too small to show on the accompanying map. One mass is represented at the big bend of the Lower White. My investigations lead to the conclusion that this granite is post-Carboniferous and pre-Cretaceous, and Dr. Dawson has determined that it is post-Triassic in age.¹

Of the more basic intrusions of the region little can be definitely stated. In the rocks of both the lower and the upper sedimentary series dikes which should be classed with this group are found. The greenstone-schists of the Upper Tanana and White have already been classed with similar schists which occur in the gneisses. The rocks here indicated as dioritic and gabbroic intrusives, probably including diabasic and other basic rocks, are almost entirely massive, and are a distinct

¹ Yukon district and British Columbia: Geol. Surv. Canada, Vol. III, 1887-88, Pt. I, p. 32 B.

series in these greenstone schists. Professors Cushing and Reid have mapped as diorites and quartz-diorites rocks of this character occurring on Glacier Bay. Along the Upper Tatshenshini I found some pyroxene-feldspar rocks which are put in this group. The innumerable dikes of this character found in some parts of the Nutzotin series have already been described. While this grouping together of rocks of such varied character is unsatisfactory, yet it is all that our present knowledge warrants.

TERTIARY ROCKS.

TOK SANDSTONE.

A small area of this rock was described and mapped in 1898, and I quote as follows from my report:

A few miles below the mouth of the Tok River several exposures of a soft, yellow sandstone were found. This sandstone, though of small areal distribution, has been given a special name because it is probably younger than any of the formations already described. It has a yellowish color, is friable, and is thin bedded. Beds of fine feldspathic conglomerate of no great thickness are found in it. The sandstone itself showed a thickness of somewhat over 50 feet at one locality.

Several basic dikes of considerable size were found cutting the sandstone at right angles to the bedding, and these were usually deeply weathered. A microscopic examination of one of the dikes showed it to be an olivine-diorite. The strike of these beds is about E. and W., and the dip, which is rolling, not over 5° or 10° . This strike is entirely at variance with that of the gneisses which are near at hand.

Fragmental plant remains were found in the Tok sandstone, but unfortunately are not well enough preserved to give any clue as to the age of the beds. From their slight deformation and unaltered appearance I am inclined to regard them as post-Paleozoic and most likely of Tertiary age.¹

While we were in the valley of the Kaskawulsh River we could see far to the south of us high escarpments of bedded rocks dipping southward, forming the front of the St. Elias Range. Interbedded with them were masses of dark intrusives, which in places could be seen to cut the bedding. This series was seen to overlies some older rocks unconformably. No opportunity was afforded to study this series, except from a distance, but it seems probable that they are of Tertiary age.

TERTIARY EFFUSIVES.

On the accompanying geological map large areas of effusives are marked as occupying the northern margin of the St. Elias Range. These rocks include rhyolitic, andesitic, dacitic, and basaltic types, but no detailed study has been made of them. Volcanic tuffs are also not uncommon, and some fragments of volcanic glass were found. The age of this series is not definitely determined. They are inti-

¹ Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, p. 473.

mately associated with volcanic rocks which have been but recently ejected, and which must be considered as of Pleistocene age. The larger masses, however, show evidence of being older and have been more or less deformed. This deformation manifests itself in monoclinical uplifts which dip south and present fault escarpments to the north. Along these escarpments evidences of crushing and shearing were found wherever opportunity was offered to study them. Along the route of travel between the Kaskawulsh and Nabesna rivers, at different points, we saw innumerable escarpments of this series, but opportunity was given for studying only the ones lying adjacent to our course. In general, it can be stated that where these effusive rocks occur along the northern margin of the St. Elias Range they appear in these faulted blocks. The type of structure is similar to that described by Russell along the southern margin of the range, near Yakutat Bay, where the fault blocks dip northward.

As our best evidence goes to show that no dynamic disturbances of this character have occurred since Tertiary times these effusive rocks are regarded as of Tertiary age. In a broad depression which connects the Upper White with the Upper Tanana there are a great number of mesas made up of volcanic material and usually capped by some hard rock. These effusive rocks exhibit a slight tilting to the south.

On the headwaters of the Tatshenshini River some effusive rocks were found which have been grouped with the others on the accompanying map. They show relatively the same amount of deformation, but in the hand specimen have the appearance of rocks considerably older. They can be conveniently grouped under the field term "felsites." With them are tuffs and conglomerates containing fragments of the Coast Range granite, showing them to be of younger age and separated by an erosion interval. At various localities in this region rocks of similar type have been found, but these have not been studied in detail. In a previous report the mention has been made of some andesitic rocks on the Lower White, and also on the Middle Tanana in the vicinity of Tok River. From their general appearance these rocks should be grouped with those of the Upper Tatshenshini, and probably represent the oldest outbursts of Tertiary times.

PLEISTOCENE DEPOSITS.

SEDIMENTS.

On the accompanying map (Pl. XLVII) the water-laid Pleistocene deposits are represented. The limit of glaciation is shown, but no attempt has been made to map the purely glacial deposits, as the region has not been studied in sufficient detail. The Pleistocene beds are, for the most part, old river gravels, lacustrine silts and sands,

together with the moraine river gravels and silts. The old river gravels have the same history and the same origin as those which are at present being laid down. In some cases the slight elevation has resulted in a new river channel being incised in the old deposits, thus giving the silt and gravel terraces which are so common in some parts of the region. In other cases these old gravels are distributed along valleys which, by the change of drainage, are now abandoned, the drainage having sought new water courses. In the study of both the older Pleistocene deposits and those which are now being laid down in the lakes and rivers, it has been found impossible to differentiate the fluvial from the lacustrine deposits. Such differentiation, in my opinion, can be made only from topographic and physiographic evidence.

EFFUSIVES.

The effusive rocks of the region have already been described and the probable Tertiary age of some of them has been considered. Some of these effusives undoubtedly belong with the Pleistocene deposits, as they are of very recent ejection. No attempt has been made on the accompanying map to differentiate the Pleistocene and Tertiary volcanics. Effusive rocks of recent age have been described from various parts of Alaska and are probably synchronous outpourings. Examples of these are the volcanics of the Wrangell group,¹ the basalt flows of White-Horse Rapids and Fort Selkirk, and the volcanic rocks of the Alaskan Peninsula, Aleutian Islands, and Lower Yukon.

GLACIAL PHENOMENA.

The glacial phenomena of the region can be differentiated into that of the present glaciers and that of the Cordilleran ice sheet. On our trip from Lynn Canal to the Nabesna River we saw innumerable glaciers which had their source in this snow range and the White River route. A few of these are shown on the accompanying map, but many it is impossible to locate (see Pls. XLI, A, and XLV, A). Among the larger glaciers which we passed were the O'Connor, the Donjek, the Klutlan, and the Tanana. These all occupy valleys of considerable size. In every instance studied by the writer the glaciers were found to be retreating. A few small glaciers were also seen in the Nutzotin Mountains, to the north of our route of travel. These are of interest because they are probably the most northerly glaciers thus far found in Alaska.

The limit² of glaciation on the accompanying map shows three long tongues extending down the valleys of the Nabesna, Tanana, and White

¹Mr. Rohn kindly furnished some information in regard to the region between the Chitina and the Upper Tanana.

²East of White River this limit of glaciation is determined by the work of Dr. Hayes, Dr. Dawson, Professor Russell, and Mr. J. B. Tyrrell, in reports already cited.

ivers. Of these, the Nabesna and White River tongues were determined by field observations; the Tanana tongue only by inference. They simply represent a valley glacier which extended beyond the ice front at the time of maximum glaciation. In the case of these valley glaciers the sides of the valleys are found to be glaciated only up to a certain limit, which gradually decreases in elevation to the northward. At the end of the valley glacier of the Nabesna River a morainic topography was observed.

It seems quite probable that there was no connection between the glaciation of the Alaskan Range and that of the St. Elias Range. From the best reports we have, the region between the Upper Copper and the Upper Tanana is not glaciated, and hence the Alaskan Range probably represented a different center, from which the ice radiated in all directions. Whether this glaciation in the Alaskan Range was synchronous with that of the St. Elias must be determined by future investigation. In the glaciated region the deposits are not plentiful; only a few exposures of till have been observed. Glacial erratics are, however, very common. At a number of localities glacial moraines were observed, but these belong very largely, if not entirely, to the present epoch of glaciation. On the accompanying geological maps no attempt has been made to differentiate the glacial from the other Pleistocene sediments.

VOLCANIC TUFF.

The white volcanic ash which is found on the Pelly, Lewes, and the Upper White has been noted by many writers, and has been especially studied by Dr. Dawson and Dr. Hayes. In a previous publication I have added some notes to Dr. Hayes's accounts of its distribution. The work of the past summer has yielded considerable information in regard to this interesting deposit, but it is not within the province of this paper to discuss it. In a westerly direction the volcanic ash has been traced far beyond what was formerly supposed to be its limits. It occurs as far west as the Forty-mile Basin and east to the O'Connor Glacier. Near the margin of the area it is found simply as a thin film immediately underneath the soil, and can be observed only when the conditions are favorable. In thickness this deposit varies greatly. On the Upper White, as described by Dr. Hayes and observed by the writer, large drifts 100 feet deep were seen, while near the margin of the region the thickness of the bed is hardly measurable. That this is a wind-laid deposit¹ is clearly shown by its distribution. It occurs on mountain tops and on valley slopes, as well as along river bottoms.

¹ Professor Heilprin's theory that this ash is a lake deposit becomes utterly untenable when the facts of its distribution are studied. It seems doubtful whether Professor Heilprin had read Dr. Hayes's paper, for the facts presented in it are sufficient to confute the theory of its being a lacustrine deposit. See *Alaska and the Klondike*, pp. 228-233.

Along the valley of the Upper White River it is distributed as huge drifts, which from a distance closely resemble snowdrifts.

The location of the volcano from which these ejecta came is not yet determined. From the distribution of the ash and the relative coarseness of the material at different localities the writer is inclined to believe that the volcano lies to the south of the Klutlan Glacier, well in the heart of the range. The Klutlan Glacier, besides carrying much ash, also brings down considerable white pumice, the fragments being sometimes 6 inches in diameter. These are probably a part of the same ejecta as the ash. Of the glaciers and streams the Donjek and the Klutlan must have their sources nearest the volcano.

It is of interest to note that at several localities two layers of ash were observed, separated by several inches of soil. This fact suggests that there were two outbursts separated by a considerable time period. In favorable localities the soil was able to gain a foothold before the second outburst. At the Klutlan Glacier some pebbles of a white volcanic rock were found, which may represent lavas of the same period of activity.

GROUND ICE.

The ground-ice formation of Alaska has been frequently described and needs no further description here. Below the immediate vegetation of the surface the ground is, as a rule, frozen throughout the year. Thawing takes place only along fresh stream cuttings or where the moss or grass has been stripped off. In some cases this ground ice is clear, resembling glacial ice, but in origin it differs little from that of the frozen soil. These clear ice masses represent small lakes which have congealed.

The dense growth of moss, which covers nearly the entire surface of the country, retards erosive action very materially. Streams are usually clear, even after rainfall, unless they have glacial origin or are undercutting silt banks. Where rocks are exposed among the higher peaks as cliffs, disintegration takes place very rapidly, probably because of the extremes of temperature.

Table of hypothetical correlations.

	Spurr; Yukon district, 1896. ¹	Brooks; Fynmud Harbor to Fortymile River, 1899.	Brooks; White and Tanana river districts. ²	Mendenhall; Reservoir Bay to the Tanana River, 1898. ³	Spurr; southwestern Alaska, 1898. ⁴	Eldridge; Sushitna Valley, Alaska Range and Cantwell River, 1898. ⁵	Schroder; Copper River district, 1898. ⁶
Pleistocene.....	Sills and gravels.	Sills, sands, and gravels. Effusive rocks in part.	Sills and gravels.	Sands and gravels.	Sills, sands, and gravels.	Sands, gravels, and boulder clays.	Sills and gravels.
Tertiary.....	Twelve-mile beds, Rampart series, Nulato sandstone, Palisade conglomerate.	Tok sandstone and effusive rocks in part.	Tok sandstone.(?)		Tyonok beds, Hayes River beds, Nushagak beds.		
	Kenai series.				Yentna beds.	Kenai series.	Orea series.(?)
Cretaceous.....	Mission Creek series.			Matanuska series.	Tordillo series, Hotchkiss series, Kolmakof series, Oklune series.		Valley series.(?)
Jurassic.....					Naknek series, Skwentna series, Terra Cotta series.		
Devonian and Carboniferous.	Tahkandit series.	Nitzotin series.	Wellesley series, Nulok beds.(?)	Sunrise series.	Tachatna series.	Cantwell conglomerate.(?)	
Silurian and pre-silurian sediments with intrusive and extrusive rocks.	Rampart series, Birch Creek schists, Forty-mile series.	Greenstone, schists, Kollo series.	Greenstone, schists, Tanana schists, Nushina series.	Greenstones, Tanana schists.		Sushitna schists.	Klutena series.
Archæan.....	Basal granite.	Gneissic series.	Gneissic series.			Basal granite and gneissic series.	

¹ Geology of the Yukon gold district, Alaska; Eighteenth Ann. Rept. U. S. Geol. Survey.² A reconnaissance in the White and Tanana river basins, Alaska; Twentieth Ann. Rept.³ A reconnaissance from Resurrection Bay to the Tanana River, Alaska; Twentieth Ann. Rept.⁴ A reconnaissance in southwestern Alaska; Twentieth Ann. Rept.⁵ A reconnaissance in the Sushitna Basin and adjacent territory, Alaska, 1898; Twentieth Ann. Rept.⁶ A reconnaissance of a part of Prince William Sound and the Copper River district; Twentieth Ann. Rept.

SUMMARY OF GEOLOGY.¹

A broad belt of crystalline rocks extends in a northeast-southwest direction in the region of the Tanana-Yukon divide, embracing a series of gneisses, mica-schists, basic schists, and various intrusives, chiefly of an acid character. Near the Middle Tanana this series bends to the west and south, and its continuation is to be sought for in the region of the Upper Kuskokwim.² To the southeast this belt is probably continued by the granitic rocks on the Pelly River, described by Dawson. What evidence we have goes to show that this is the basal series of the Yukon Basin, and as it contains no recognizable detrital material it can properly be assigned to the Archean. Whatever the original character of the rocks may have been, they are now essentially mica-schists and gneisses, with considerable intrusive material. The gneisses and schists, and in part the intrusives, have been subjected to intense dynamic metamorphism. Their metamorphic condition is the strongest argument for considering them older than any of the sedimentary rocks. The intrusives are both sheared and massive and hence were injected both during and after the period of folding.

After the era of the folding of the gneisses the next important epoch in the region is that during which the older sediments, the Kotlo series, as marked on the accompanying map, were deposited. The oldest rocks of this series contain more or less detrital crystalline material, and it is probable therefore that during this epoch a part of the Archean area was exposed as a land mass, and was, in part at least, the source of the sediments. The oldest rocks of the series are present—quartz-schists with impure limestones, called the Birch Creek series by Spurr (Tanana schists, Brooks). This series aggregates many thousand feet in thickness. This period was followed by the deposition of an immense thickness of limestone beds.³

Acid and basic rocks are found in both the arenaceous and calcareous beds. The close of the deposition of this calcareous series was marked by dynamic disturbances, and these beds were folded, and probably during this time the intrusion of the igneous rocks took place.⁴ After the dynamic forces had become quiescent once more, these older series, in part, formed land masses, which contributed sediments. A stratigraphical break is here marked by the unconformity below the Rampart⁵ series and greenstone-schists, which constitute the upper member of the Kotlo series. This epoch was characterized by the extrusion and intrusion of a vast amount of igneous

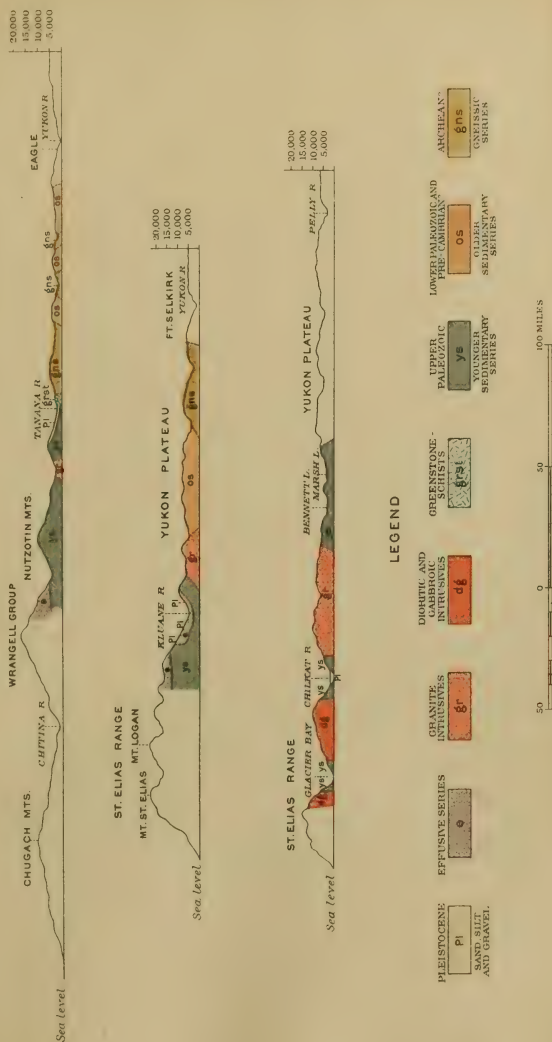
¹ See Pls. XLVII and XLVIII.

² Spurr's crystalline rocks of the Kaiyuh Mountains, which he regards as basal, seems to be a distinct belt lying to the northwest of the one under consideration: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, p. 241.

³ Fortymile series, Spurr, and Nasina series, Brooks.

⁴ Geology of the Yukon gold district, pp. 255-256.

⁵ Spurr, *op. cit.* The greenstone-schists have been provisionally correlated with the Rampart series.



PROFILES OF ST. ELIAS RANGE AND YUKON PLATEAU WITH GEOLOGY AS FAR AS KNOWN

BY
ALFRED H. BROOKS

rocks, chiefly of a basic character. This upper member of the Kotlo series is believed to belong to the lower Paleozoic. To the east of the areas mapped the Kotlo series has not been recognized, while to the west Spurr has identified them in the Birch and Mynook Creek basins. The series is of the utmost importance because the gold of the Yukon district, so far as determined, has been derived from the mineralized zones found in it.

The Nutzotin series is the next succeeding formation marked on the accompanying geological map. This series is of Devonian and Carboniferous age, and, as determined in the Fortymile¹ and upper Tanana basins, overlies the Kotlo series unconformably. This unconformity was rather one of erosion than of deformation. The older rocks were in part above water and contributed sediments while this series were being deposited.

I have described the heavy conglomerate of the Wellesley formation in the upper Tanana and White River region,² which there represents the basal member of the Nutzotin series. These are succeeded by black slates, which are overlain by impure limestones. Above these is a considerable thickness of gray and greenish slates and graywackes, growing more calcareous upward, and with them is a great quantity of basic intrusives, together with tuffs and extrusive rocks. These igneous rocks can be conveniently grouped together under the field term greenstones until they have received careful microscopical determination. The uppermost member of this series is a bed of limestone probably exceeding a thousand feet in thickness, which is usually highly crystalline. This slate, limestone, and greenstone series was traced eastward along our route of travel to Lynn Canal. Reid and Cushing have described the sedimentary rocks of the Muir Glacier region as argillites and limestones, and these have been provisionally correlated with the Nutzotin series on the accompanying map. The rocks lying adjacent to the Coast Range along the Lewes River route, as determined from descriptions by Dr. Dawson and from personal observations by myself, undoubtedly belong to the same series, and have been so colored on the accompanying map.

Fossils have been found in this series at several localities, so that its position in the stratigraphical column is approximately determined. On the Yukon Spurr³ has found an upper Carboniferous fauna. On the Tanana⁴ fossil evidence goes to show that this series is Devonian or Carboniferous. The Glacier Bay⁵ limestones have been proved to

¹ Spurr's Tahkandit series is included in the Nutzotin series. For the distribution and relation of the Tahkandit series see Spurr's report.

² Op. cit., pp. 470-472.

³ Op. cit., p. 170.

⁴ A reconnaissance in the White and Tanana river basins; Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, p. 472.

⁵ Glacier Bay and its glaciers, by Harry Fielding Reid; Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 433-434.

be of Carboniferous age. Dr. Dawson¹ has found Carboniferous fossils in the limestones of Tagish Lake north of the Coast Range. These facts show that the Nutzotin series is largely Devonian and Carboniferous, but as represented on the accompanying map it may include older beds.

No Cretaceous rocks are represented on the geological map, though it is quite possible that they may be found on more detailed examinations.² Dr. Dawson has determined some areas of Cretaceous along the Lewes River, notably on Lake Lebarge. Spurr's Mission Creek series of the Yukon district is believed to be of Cretaceous age. These Cretaceous rocks, as shown by these writers, are thrown into open folds.

Intrusives are common throughout the series which have been so far described. They can be classed as rocks of granitic, dioritic, gabbroic, and diabasic character. The largest mass of intrusive rock is represented by the Coast Range granite. This is a medium-grained hornblende- and biotite-granite of a rather uniform character. At Lynn Canal this belt is about 60 miles wide. To the northwest a similar granite was found near Lake Kluane and on the Nabesna. It seems probable that the belt is continuous, though it has not been traced by field observations. To the southeast Dr. Dawson has traced this granite as far as the Stikine River. The investigations of the writer lead him to believe that the granite is post-Carboniferous and pre-Cretaceous. Dr. Dawson³ has determined that it is post-Triassic in age. In the section across the White and Chilkoot passes some shear zones are observed in the granite, along which it has been altered to a mica-schist. This goes to show that some dynamic disturbances have taken place since the intrusion of the granite.

A second class of intrusives, which are shown on the accompanying map, are classed as dioritic and gabbroic in character. The only large area of this type shown is that of the region of Muir Glacier, which is taken from Professor Reid's geologic map. These rocks are believed to be younger than the granite, in which are found dikes of the same character.

Of Tertiary sediments we have only one small area in the region. This is the so-called Tok sandstone, found near the mouth of the Tok River, the beds of which are gently undulated.

The large belts of effusive rocks shown on the geological map are probably but the scalloped margins of much larger areas occurring to the south. This is shown by the abundant volcanic material brought down by the streams and glaciers which have their sources in the mountains of that region. In the Wrangell region we have more

¹ Exploration in Yukon district, Northwest Territory, and in British Columbia, p. 33 B.

² Jurassic fossils were found by Hayes south of the Skolai Pass (op. cit., p. 140), and beds which were probably Jurassic are reported by Rohn from the Wrangell region.

³ Op. cit., p. 32 b.

definite information of the occurrence of large masses of effusive material.¹

No study has been made of the various effusive rocks which were collected by me, but a hasty examination showed rhyolitic, andesitic, dacitic, and basaltic types. Tuffaceous rocks are very common, and some fragments of volcanic glass were found near the Klutlan Glacier.

No attempt has been made on the accompanying map to differentiate the volcanics of different epochs. In general it can be stated that the outburst began in late Tertiary times and probably reached its maximum development in comparatively recent times. Some of the volcanoes of the Wrangell group are still smoking, but it is not known whether or not this is simply a temporary quiescence or the solfataric stage which precedes the complete cessation of activity. To the north of the region mapped small areas of recently extruded rocks are not uncommon. As examples, we have the basalt of White Horse Rapids, at Fort Selkirk, and at various other points on the Yukon. One of the manifestations of recent volcanic activity is the white volcanic ash whose wide distribution has already been referred to.

The volcanic rocks of the northern margin of the St. Elias Range and of the upper White River show evidence of having suffered some disturbance. To the south of our route of travel, between the Donjek and the White, we could see a number of northward-facing escarpments, the nearest of which was determined by actual observations to be made up of volcanic rocks; the others, lying to the south, were of a similar character, so far as could be determined by examination with field glasses. The tops of these escarpments are moss and grass covered and slope gently southward in conformity with the bedding of the constituent rocks. At several points the most northerly escarpment was examined and the rocks were found to be much sheared and shattered. This evidence goes to show that faulting has taken place along the escarpments, and that, in fact, these are monoclinical blocks tilted to the south and faulted on the north side. In the broad depression which connects the upper White with the upper Tanana there are a great number of mesas formed of volcanic material and usually capped by some hard bed. In these the strata also show a tilting to the south.

The history of the unconsolidated Pleistocene deposits has been referred to in the physiographic notes, and has been somewhat more fully discussed in a previous publication. At only one locality in this region was there any evidence of the deformation of the unconsolidated beds, such as has been noted elsewhere in Alaska. In the mud flats at the mouth of the Slims River at the head of Lake Kluane, some silt beds were observed which rise above the general level of the flood plain

¹ Messrs. Hayes, Allen, and Rohn.

in a series of little hummocks. On examination the material was found to be a finely banded blue clay which had been thrown up into a series of gentle folds. This folding may have been produced by some local cause and not by a deformation due to dynamic forces. In general, during Pleistocene times the dynamic disturbances have been orographic elevations and depressions rather than deformations.

The geological history of the important orographic features of the region has already been referred to, but a brief summary is necessary for the sake of emphasizing certain leading features. The Yukon Plateau is a dissected upland plain lying between two great mountain systems. On the north it is bounded by the Rocky Mountain chain which lies between the Mackenzie and Yukon basins. This chain has a northwesterly trend nearly to the Arctic Ocean, then makes an abrupt turn to the west and continues parallel to the frozen sea. Its westward extension, which decreases very much in elevation, probably reaches the sea in the vicinity of Cape Lisburne. This part of the Rocky Mountain chain is practically unexplored.¹ It is, however, known that the Paleozoic column is represented in northern Alaska² as well as the Cretaceous, and there is at least no evidence against a correlation of this northern range with the Rocky Mountains.

To the south the Yukon Plateau is limited by several distinct ranges. The most westerly of these is the great Alaskan Range, which lies west of Cook Inlet and the Sushitna Valley and extends in a northeast direction to the Tanana. This range, so far as known, is largely made up of metamorphic schists, which should probably be included in the older sedimentary series of the accompanying map. To the east of the Alaskan Range the boundary of the plateau is continued by the Mentasta and Nutzotin mountains. These, as has been shown, are composed of the younger sedimentary rocks—the Nutzotin series. Still farther east the plateau is bounded by the St. Elias Range, the geology of which is but little known. The rocks of the Chugatch Mountains, a branch of the St. Elias Range lying to the south of the Chitina River, Schrader regards as probably Cretaceous. The beds exposed near Skolai Pass Hayes determined as Mesozoic or younger. At Yakutat Bay Russell³ found Pleistocene beds, and at Lituya Bay Dall⁴ reports phyllites and granite overlain by sandstones and conglomerates, probably of Miocene age. Beds of Miocene age have been found between Controller Bay and Icy Bay on the southeast coast of Alaska.⁵ At Glacier Bay Reid and Cushing found Carboniferous limestones overlying phyllites of undetermined age.

¹The northern portion of the Canadian Rockies has been studied by R. G. McConnell. See *An exploration in the Yukon and Mackenzie basins*: Geol. Surv. Canada, Vol. IV, 1888-89, Pt. II.

²Report on Paleozoic fossils from Alaska, by Charles Schuchert: *Seventeenth Ann. Rept. U. S. Geol. Survey*, Pt. I, pp. 899-900.

³*Nat. Geog. Mag.*, Vol. III, 1891-92, p. 167.

⁴*Seventeenth Ann. Rept.*, Pt. I, p. 784.

⁵A reconnaissance in southwestern Alaska, by J. E. Spurr: *Twentieth Ann. Rept. U. S. Geol. Survey*, Pt. VII, pp. 263-264.

In the extension of the St. Elias Range to the southward Paleozoic and younger rocks have been found. The studies of the writer have shown that there are Carboniferous rocks along the northern margin of the range overlain by Tertiary or recent volcanics. The evidence, fragmentary as it is, points to the conclusion that while the coastal region of the St. Elias Range has been uplifted during Pleistocene times, as Professor Russell has shown, yet there was a much older protaxis, and that the range is in part made up of older rocks. That a part of the range is considerably metamorphosed compared with the coast belt is shown by the garnetiferous schists which have been reported among the glacial *débris* brought from the mountains, both at Yakutat and at Glacier Bay. The Coast Range, as has been shown, is a large mass of granite which was intruded in late Cretaceous or early Triassic times.

MINERAL RESOURCES.¹

GOLD.

Most of the region under discussion lies without the gold belt of the interior of Alaska, and we did not see the rocks of the gold-bearing series until we reached the Fortymile basin. Much of the area included in the accompanying geological map is occupied by rocks younger than those which have made the Fortymile region and the Klondike so famous. This series of rocks, however, has been locally found to be highly mineralized and to carry some gold. It seems probable, from the best accounts, that the gold-bearing rocks of Atlin probably belong to the horizon of the younger sediments, as marked on the accompanying map—the Nutzotin series. There can be but little question that the rocks of the Porcupine gold district, in Chilkat River basin, belong to the Nutzotin series. It seems probable that the Shorty Creek district of the Kashaw River basin also derives its gold from this series.

Considerable panning was done by our party as opportunity offered, and colors were occasionally obtained, but I am forced to the conclusion that the regions west of Dalton House, as far as the Fortymile basin, will never produce gold in commercial quantities. From accounts given by prospectors the Shorty Creek district does not seem to have turned out as well as had been expected last year. Some brief statements in regard to this district were published by Mr. Russell L. Dunn,² from whom I quote as follows:

What has generally been referred to as the Shorty Creek district is in the singular isolated mountain mass of metamorphic Jurassic slates lying west of Lake Desardeash, 150 miles inland from Pyramid Harbor and accessible by the Dalton trail.

* * * Shorty Creek, though gold bearing and the locus of the first discovery, does not seem to contain commercial values. * * * The district is, on the whole, not

¹ See Pl. XL.

² Mining and Scientific Press, October 29, 1898, p. 425.

one to which prospectors can go expecting to make a strike in the first season, nor even to anticipate very rich mines in. Miners, however, can make fair wages from many claims; incidentally they may discover something worth the attention of capital.

Our expedition passed some 10 or 12 miles to the south of Shorty Creek, but I was unable to visit this locality. I am not inclined to agree with Mr. Dunn in regard to the Jurassic age of the slates, and these are represented on the accompanying map as belonging to the Nutzotin series, which is of Upper Paleozoic age.

It will be seen that this belt of rocks, as a whole, is not gold bearing, yet it frequently is mineralized and in some places, as on Porcupine Creek, which will be described below, and possibly at Shorty Creek, may carry gold in commercial quantities.

PORCUPINE GOLD DISTRICT.¹

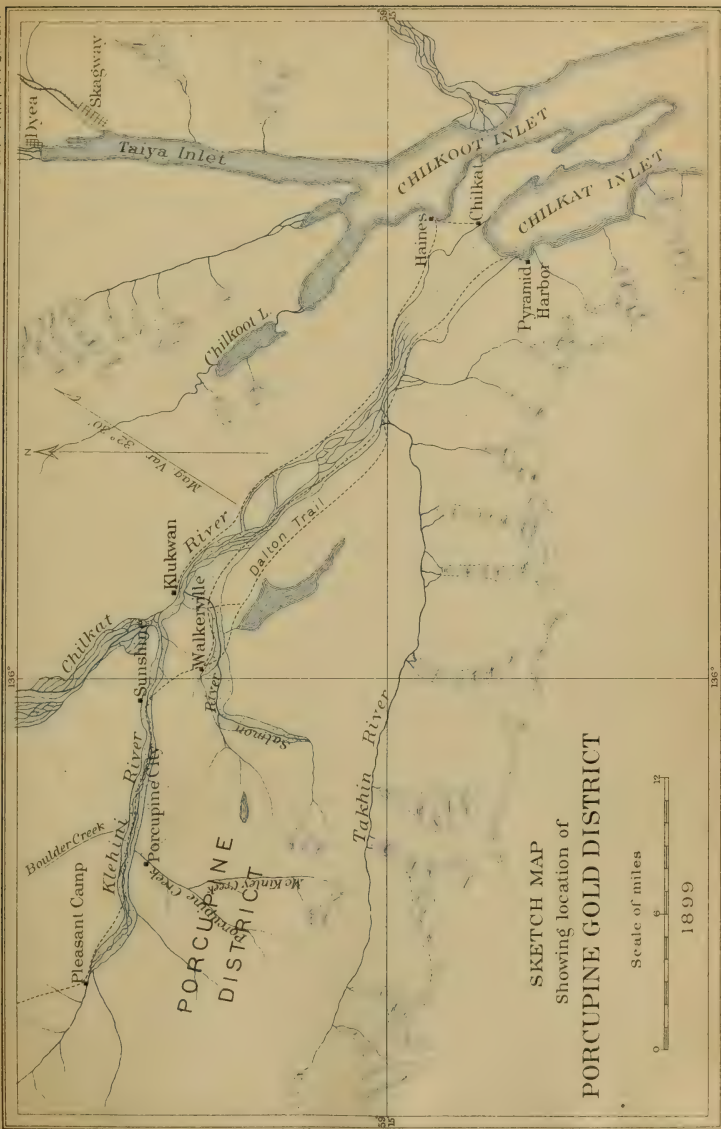
This district lies on Porcupine Creek, which joins the Klehini River about 35 miles from Pyramid Harbor and 7 miles below Pleasant Camp. During the brief visit made in June, 1899, only a few general facts could be gathered in regard to this district, for the upper courses of the creeks were then deeply buried in the snow.

Near the mouth of Porcupine Creek there is a belt of white crystalline limestone which strikes about northwest and southeast, and has steep dips, usually southwest. It is often much sheared and faulted, and the bedding is obscured. The belt is less than half a mile wide, and above it is a broader belt of clay slates which are usually highly contorted. The strike of the slates is about N. 20° W., and hence at variance with that of the limestone. There would seem to be an unconformity here, though the region is so much faulted that the structural relations can be determined only by a closer study than I was able to give.

In the stream gravels are found abundant pebbles of hornblende-granite, diorite, and quartz-diorite, and of some more basic rocks. None of these rocks were found in place and in only one locality were any dikes observed—about 2 miles from the mouth of the creek, where a deeply weathered grayish dike rock was found cutting the slates and locally altering them to a hornstone. The dike, so far as could be determined, was of dioritic character.

There is a marked absence of quartz veins, both in the bed rock and in the stream gravels of Porcupine Creek. I found a few pebbles of vein quartz in the creek bed, but saw absolutely none cutting the slates. Calcite veins are, however, not uncommon in the slates and are frequently charged with pyrites. The slates, as a whole, are highly mineralized and assays from average samples showed that they carry traces of both gold and silver. Even though my visit was a very hur-

¹ See Pl. XLIX.



SKETCH MAP
Showing location of
PORCUPINE GOLD DISTRICT

Scale of miles
0 2 4 6 8 10 12
1899



ried one, I saw enough to convince me that the gold of the placers was derived from these mineralized slates. Such being the case, the extent of the district will depend on the width of this slate belt, which I was unable to determine on account of the snow. It is possible that the entire belt is not mineralized, and this fact should be borne in mind by prospectors. According to such facts as I was able to gather, I am led to believe that toward the headwaters of the creek there are large masses of granite and other intrusive rocks, probably similar in character to those already referred to on Glacier Bay. Coarse gold has been found on McKinley Creek, a tributary of Porcupine Creek.

The placers that were being worked on Porcupine Creek during my visit were irregular benches which are formed of large boulders more or less irregularly tumbled together. These stream benches can not be traced a great distance and are apparently due to the damming caused by rock barriers. The best pay dirt has been found above these rock barriers, among the large boulders and gravels which have been deposited by the stream and contributed by the talus from the slopes of the valley. The presence of these very large boulders, sometimes several feet in diameter, very much increases the cost of working the claims. The bars of the creek itself can be worked only at considerable outlay, because of the difficulties of getting rid of the water. The Porcupine gold rates high in value as far as known, is rather pure, and the grains are usually very flat, as would be expected of gold derived from mineralized slates. The pay dirt, so far as my observations go, is from 2 to 4 feet thick and lies on bed rock. A pan of gravel which I washed out from one of the claims yielded about 20 cents in gold in 5 different grains. I was informed that pans running 60 to 80 cents are not uncommon, and that the largest nuggets have been from \$3 to \$5 in value. Since leaving there I have been informed that the attempt was made to reach bed rock in the bed of the creek and that the miners passed through 18 feet of gravel without reaching the bottom. These gravels were said to have all carried values.¹

Since my visit discoveries have been reported in the Salmon River Basin, east of Porcupine Creek, and on Glacier Creek, west of Porcupine. I have no definite information that there have been any placers of commercial value found outside of the Porcupine Valley, but would rather expect that the northeast and southwest extensions of the gold-bearing series would yield placers. The Porcupine district was discovered in June, 1898, by Messrs. Mix and Finley, who located the Discovery claim about 2 miles from the mouth of the creek.² They are said to have taken out some \$1,500 during the season.

¹ Mr. W. H. P. Jarvis, of Bennett, British Columbia, informs me that since my visit 16 feet of pay dirt has been found on Porcupine Creek, giving \$50 a day to the man. He estimates that the district produced some \$60,000 during the past season, but states that there is no official basis for these figures. The output in the coming season will undoubtedly be very much greater, as in 1899 much of the time and energy of the miners was given to prospecting rather than to the development of the claims.

² According to another statement the credit of the discovery belongs to E. Hackley.

The Porcupine district is easily accessible from the coast. Its open season is rather long, extending from June to September. The Dalton trail will enable miners to carry in provisions at no very great expense. Even if it is not so rich as some of the other placer regions of Alaska it possesses some advantages over those of the interior, and if it turns out as well as it promises we may expect it to continue to be a gold producer.

FORTY-MILE GOLD REGION.

The first discoveries in gulch placers were made in the drainage basin of Fortymile River in 1886, and since that time the work of placer mining has been continuously carried on in the basin. This region has been reported on by Mr. Spurr,¹ and it is my purpose to give here only a few supplementary notes which were gathered on the recent trip.

Fortymile River joins the Yukon about 30 miles above the international boundary, and its mouth is, therefore, in Canadian territory. Its drainage basin is, for the most part, on the Alaskan side of the line, as are also most of its gold placers, so far as determined. The gold, as shown by Spurr, is derived from metamorphosed sedimentary rocks, which he divided into three formations. On the accompanying geological map these are all included in the Kotlo series. The derivation of the gold is from quartz veins and from zones of impregnation, but up to the present time there have been no discoveries of veins reported which would warrant the introduction of mining machinery.

Important creeks, from the standpoint of the gold prospector, are Napoleon, Chicken, Franklin, and Canyon creeks, as well as Nugget Gulch. All of these have produced gold in commercial quantities. There are innumerable smaller creeks and gulches which have been worked, many of them quite successfully, but most of them are not so rich as those that have been named.

The important discovery of the past year has been Wade Creek. Wade Creek joins Walker Fork about 5 miles from South Fork. Its drainage basin lies immediately south of the trail leading from Franklin Creek to Steele Creek, and the valuable discoveries are said to have been made in the upper half of the basin. The pay streak is said to be rich but not very thick, and lies on bed rock some 12 or 14 feet below the surface. Bench claims as well as creek claims are being worked. I was not able to visit this creek in person, and these facts were gleaned from various sources. As to the value of the claims I can give no definite information, but well-authenticated rumors state that fractions of claims had sold at from \$30,000 to \$40,000. The creek basin lies within the gold-bearing series and there seems to be a strong probability that this is the same series in which

¹Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III. Also, Explorations in Alaska in 1898.

the famous Klondike gold occurs. There is every reason to believe, therefore, that it has an important future as a gold producer.

Like many of the creeks of the Fortymile Basin, Wade had long been prospected and had been reported as not carrying values. This is probably accounted for by the fact of the great depth to bed rock. The discoveries are said to have been made in March, 1899, and a steady influx of prospectors took place during the spring and summer months. The creek is easily accessible by a good trail from the mouth of Steele Creek, a distance of about 12 miles. Steele Creek can be reached by a trail which comes from Eagle City or by a small boat up Fortymile River from the Yukon. In the latter case prospectors will pass the United States custom-house at Sam Patch's, and will have to pay duty on their outfits unless they can prove that they were purchased in American territory.

Though the Fortymile Basin has been more or less prospected during the last fifteen years, and especially since the Klondike rush, yet it still offers a field for those who are willing to spend money and time in more detailed investigations. In the past the high price of provisions and the uncertainty and expense of transportation compelled the prospector to confine his attentions to deposits which would give immediate return. The conditions now are becoming more settled, more or less of the element of boom having been eliminated, and there is strong hope that careful prospecting will develop other gold placers in the Fortymile region.

Of the other gold districts of this part of Alaska, Sixtymile River continues to attract a good many prospectors and to yield return for work expended, some of the claims on American Creek, near Eagle City, continuing to be gold producers. I saw a nugget valued at \$192 which had been taken from a claim on American Creek in September, 1899.

COPPER.

Copper was probably the first metal which was reported from the Territory, for as far back as 1741 the Bering expedition found evidence of its use among the natives of the southeast coast of Alaska.¹ It seems to have been extensively employed among the aborigines of Alaska, for many of the native languages contain a word signifying copper when they lack a name for either iron or gold. The Copper River took its name from the fact that large copper deposits were reported to occur on its banks.² The natives of the Copper River, the Upper White, and the Upper Tanana have long been known to have access to native copper deposits, and it is probable that all the native copper in circulation previous to the ingress of the white traders was obtained from these natives. The natives used it for arrowheads and

¹ Dall, *op. cit.*, p. 272.

² Report on population and resources of Alaska, p. 77, Tenth Census.

later for bullets, and, it is said, for cooking utensils, and when the coast was first visited by white men copper knives were said to be still in use. Not having any other metal than copper they adapted it to various purposes. The extent to which the intertribal trade in copper was carried out is witnessed by the fact that copper utensils are in use by the Haida Indians of Queen Charlotte Islands.¹ These copper utensils of the Haida Indians were obtained by barter with the Chilkats, who in turn secured the copper from the Indians of the interior, probably of the White River. At the present day copper has a comparatively limited use among the Alaskan Indians. They still use it for arrowheads, but these have been largely supplemented by firearms. As most of them now use breech-loading rifles, they have no reason for manufacturing bullets of copper. Moreover, it is probable that the copper accessible to the natives has been very largely exhausted. Their crude methods of digging enabled them to obtain it from the placers only close to stream cuttings, and at present larger pieces seem to be relatively rare. An interesting fact in connection with the native use of copper is that the placer deposits, which will be described below, are situated in gulches and valleys which were up to very recent time occupied by glaciers. As the glaciers gradually retreated they would leave the gravels uncovered and make the copper contained in them accessible. The time can not have been far distant when these valleys were filled with ice down to the main river valleys, and the copper contained in them can not have been in use by the natives more than a few centuries at most.

RAINY HOLLOW COPPER DEPOSITS.

On the accompanying route map (Pl. XL) three copper belts are located. The most easterly of these is 10 miles from Pleasant Camp, at what is called Rainy Hollow. At this locality, which is about 3 miles off the Dalton trail, near the head of Klehini River,² a copper vein was discovered late in the summer or early in the fall of 1898. At the time of my visit much of this region was deeply buried in snow, and there was no opportunity for detailed investigations. The belt lies close to the contact of the Coast Range granite and the sedimentary rocks. The sedimentary rocks are quartz-schists, often calcareous, striking about N. 60° E. and dipping very steeply southeast.³ The "Discovery" claim consists of two different veins, 2 feet and

¹ Dawson: Geol. Surv. Canada, Report of Progress, 1878-79.

² This region is included in the Cassiar Mountain district of British Columbia. The name "Copper Blow division" has been suggested, but I trust that it has not yet been accepted by the Canadian authorities.

³ Mr. J. P. Jarvis, of Bennett, British Columbia, who had opportunity to study this region after the snow left the ground, says that on the Montana (the Discovery claim) there are a number of stringers of bornite embracing a zone of 300 feet in the slates and calcitic rocks. Mr. Jarvis also reports large deposits of zinc and lead from the same region. These, he states, occur in a belt about 3 miles long, running parallel to a belt of granite. The ore is said to run 33 per cent lead, 22 per cent zinc, and a little copper. Some specimens sent to me showed zinc blende and galena with a calcitic gangue.

18 inches in width. The copper minerals are bornite, chalcopyrite, and malachite. The wall rock is a hornstone, which seems to have been silicified at the time of the intrusion of the copper-bearing solutions, and probably contains more or less copper-bearing minerals. The assays of copper ores from this region which were shown me by prospectors run from 20 to 55 per cent copper. From none of them, however, could I get definite information as to whether they were average samples. My visit to this locality was simply the utilization of a day in which we had to rest our horses, and the observations were very limited. From talking to several prospectors who had been in the region for some time and from examining the specimens, I gathered that there were other veins of relatively greater importance than the Discovery veins. The general appearance of the rocks, so far as my observation goes, is that a great deal of mineralization has taken place. Quartz veins carrying copper minerals are not uncommon in the metamorphic slates and schists exposed along the Upper Klehini River.

While my own investigations can not lead to any definite conclusions, yet I would regard the region as one worthy of attention by those seeking copper. It is easily accessible from tide water, being only some 50 miles from a good harbor, and could be easily reached by a railroad up the Klehini River, the highest point which would have to be crossed being about 2,000 feet in elevation.

This mineral belt has not been traced west of Rainy Hollow. Tyrrell, however, reports some copper pyrites bearing quartz from near Glacier camp, about 15 miles west, on the Dalton trail.¹ In the débris brought down by the O'Connor Glacier I observed much mineralized quartz carrying both iron and copper pyrite, and with it numerous fragments of white crystalline limestone as well as a variety of igneous intrusives. As the Rainy Hollow mineral deposits seem to be the result of contact phenomena between calcareous sediments and igneous rocks, the westward extension of the contact would seem worthy of investigation.

KLETSAN COPPER DEPOSITS.²

Kletsan Creek,³ from which this deposit takes its name, is an unimportant tributary of the Upper White River, which joins the latter stream about 5 miles above the international boundary (see Pl. L). This stream rises in a glacier which occupies the north slope of Mount Natazhat, a peak of the northern portion of the St. Elias Range. These copper deposits have long been known to the natives, and seem to have been the source of much of the copper which is in circulation among the Alaskan Indians. The marvelous tales told by the Indians living

¹ Summary Report, 1898, p. 46, Geol. Surv. Canada.

² See Pl. L.

³ Kletsan is the White River Indian word for copper.

adjacent to this region of the wonderful "copper mountain" are important contributions to the earliest works of fiction concerning Alaska.

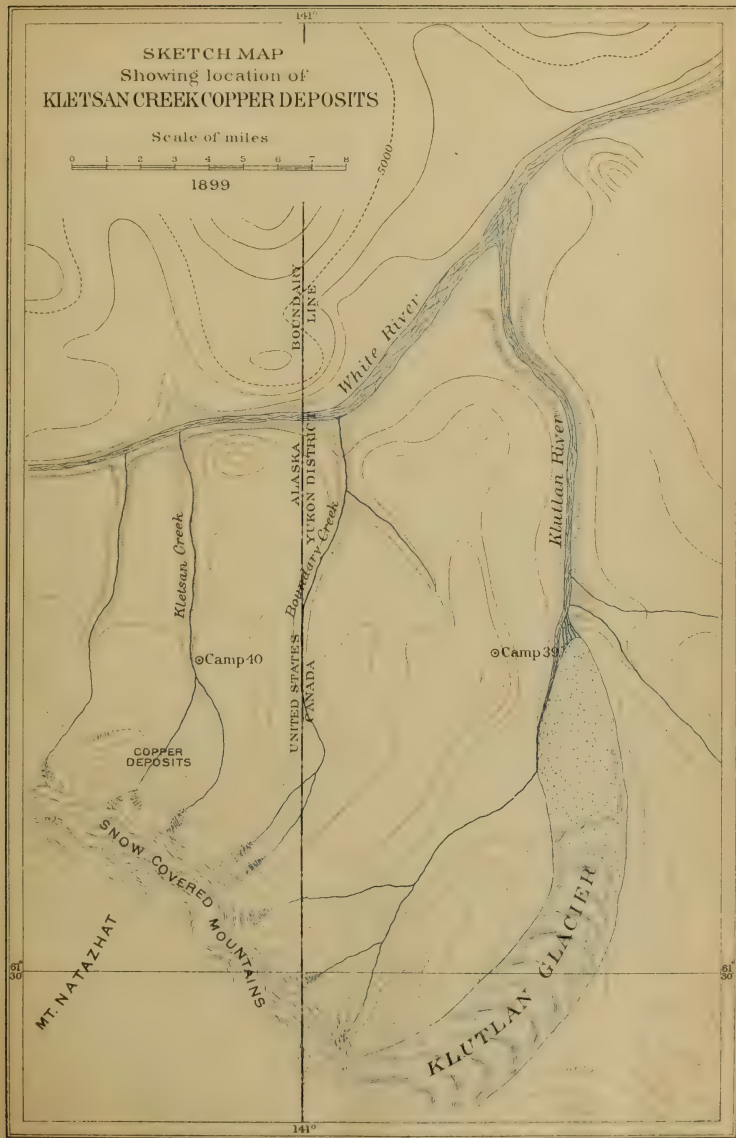
Though stories of these rich copper deposits had long been known to the traders and pioneers of Alaska, the region was so inaccessible that no attempt had ever been made to visit the copper deposits up to 1891. In that year Dr. Hayes, in company with Lieutenant Schwatka, made a trip from Fort Selkirk to Skolai Pass, before referred to.¹ In the course of this trip they were taken by the Indians to the copper deposits of Kletsan Creek.² In 1898 Mr. Jack Dalton, accompanied by Mr. Henry Bratnober, visited Kletsan Creek and procured samples of the native copper from the placer deposits.

The mountains lying to the south of Kletsan Creek are rugged and snow covered, the highest peaks probably reaching an elevation of 15,000 feet. The streams all have glacial sources, and in their upper courses flow through narrow rock-cut valleys. After leaving the base of the mountains they enter a broad gravel-filled area in which they have incised deep channels. In general, this upland consists of a series of more or less well-defined benches interrupted by numerous small lakes and undrained depressions. These are, in part, of glacial origin, but are also, in part, due to the obstruction of the minor drainage caused by the deposition of a large amount of white volcanic ash, a description of which has already been given. The talus slope of the mountains is connected with the upland by a gently sloping plain which owes its origin to a series of fan deltas formed by the streams that flow down the mountain gullies, the smaller ones only during the periods of rain.

The geology of the region, so far as studied, is not very complex. Close to where the creek leaves its rocky floor there is exposed a belt of white crystalline limestone containing numerous fossils, which show it to be of Carboniferous age. Above the limestone are found a series of carbonaceous schists and shales, which sometimes approach an impure coal in character. Both the limestone and the shales are cut by dioritic and diabasic rocks, which are exposed along the creek in large areas. The diorites seem to be the older intrusions, and are in turn cut by diabases. As far as determined from the talus and stream gravels the mountains themselves are made up of effusive rocks, which overlies these unconformably. The Carboniferous rocks show great variety in strike and dip. In some places they lie nearly horizontal, and again they are sharply folded. The strikes vary from north and south to nearly east and west. The greenstones are jointed, but are not much sheared. The slates and limestones are locally faulted, but

¹ Nat. Geog. Mag., Vol. IV, 1892, pp. 1-45.

² Another party of prospectors, under the leadership of Mr. Emmons, is said to have visited this copper belt in 1898. Several other parties of prospectors who reached the White River by way of Skolai Pass may also have visited the deposit.



usually the dips do not exceed 20° and 30°. Near the contact with the greenstone the limestone is much altered, and the bedding planes are obscure.

The placer copper deposits (all native) are contained in stream benches that owe their existence to rock barriers through which the streams have now cut their courses. The placer copper, as far as observed, is confined to a distance of about half a mile above the point where the creek leaves its rocky canyon. The placer copper is irregularly distributed on the bed rock in the crevices and also among the large boulders. The nuggets found by the Indians who accompanied me seldom exceeded a few ounces in weight, though one was found which weighed 5 or 6 pounds, and another which I saw from the same region weighed 8 or 10 pounds. The Indians dig the copper with caribou horns, and by this primitive method of mining must confine their efforts to the recent stream cuttings.

As far as the limited time would permit a careful search was made for evidence as to the source of this native copper. An examination of the greenstones showed them to be traversed by an irregular system of joints, and calcite veins were observed which followed these joints. A careful examination showed that some of these veins carried native copper. These copper-bearing veins were found close to the contact with the limestones. Calcite veins were also found in the white crystal line limestone near the contact with the greenstones. A superficial examination of the greenstones showed that they are of a dioritic character and are cut by a series of aphanitic dikes which are provisionally classed as diabases. The presence of amygdaloidal greenstones (probably andesites) and some tufas among the stream gravels suggest that these basic intrusives may be the feeders or apophyses of outpourings of volcanic rocks. No other copper minerals except secondary malachite were found during the day spent in investigating the deposits. In the western extension of the copper belt amygdaloidal greenstones carrying amygdules of copper pyrite and various gangue minerals are not uncommon. To the east the Kletsan copper belt was traced only to the vicinity of the international boundary. Its eastern extension beyond this point, if it exists, is to be sought north of our route of travel. To the west the same zone seems to extend to the Upper White River. The streams entering the Upper White River flow from the south. As far as examined all carry copper colors, and the gravels are similar in character to the rocks of Kletsan Creek.

TANANA-NABESNA COPPER DEPOSITS.

A third belt of copper deposits was found along the route of travel between the Tanana and Nabesna. The region between the two belts is occupied by the young volcanic series, so that if the copper zone is present it is buried under these younger rocks. In this belt the

evidence of the presence of copper was the same association of rocks as on Kletsan Creek and the presence of copper colors in the streams. Copper pyrite was found in the amygdaloidal greenstones, but not veins of native copper, as at Kletsan Creek. I am convinced that this is an extension of the same copper belt and that by further search copper deposits will be found. Native copper nuggets were brought to us by Indians who claimed to have found them in the region between the Tanana and the Nabesna. My investigations did not extend west of the Nabesna River, but I was informed by prospectors that "copper float" had been found in the Mentasta Mountains and also near the northeastern limit of the Alaskan Range.

DEVELOPMENT OF COPPER.

The question of the commercial value of these copper deposits is one that could not be settled in a hasty reconnaissance. The two copper belts are each about 40 miles long, with possibilities of their extending in both an easterly and westerly direction. As to the size and depth of veins which may be found no opinion can be given, and it remains a question for future investigation. Such few facts as were collected in regard to the origin of the copper do not lead to the conclusion that the deposits would be of a superficial character. They are essentially contact phenomena. If a railway is ever built into the region it will naturally be constructed from Valdes, which is 200 miles away and is the nearest harbor. Such a railway might also give access to the reported copper deposits of the Chitina River. In any event I am of the opinion that this upper region is one that is worthy of careful investigation by the prospector and the capitalist.

COAL.

Coal has been reported from the region of the Upper White and Tanana rivers, but during our reconnaissance of the past season we saw no beds of coal which would be of commercial value. At a number of places carbonaceous shales of Carboniferous age were found, but none of these were sufficiently pure to use for fuel. One of these was about 10 miles west of the Kershaw River, near our route of travel. At this locality beds of carbonaceous material some 20 or 30 feet in thickness was exposed. Much of it had been altered to graphite by dynamic metamorphism. Near the upper end of Lake Kluane similar beds were found. On Kletsan Creek carbonaceous shales containing a little bituminous coal were found, but the coal was too impure to have any fuel value. The productive coals of Alaska have thus far been found in younger beds, and so far as known no coals of value have been found in the Carboniferous of this part of the continent. The outlook for coal is not encouraging, but should the region ever be

developed it is possible that locally some of the carbonaceous beds might have fuel value.

The coals of the Upper Yukon have been described by Mr. Spurr and others. They are chiefly lignites of Tertiary age. Those that are accessible have been considerably mined for use on the Yukon River steamers. On the South Fork of Fortymile River considerable coal débris was found among the stream gravels. This was of a lignitic character, similar to that of the other Tertiary coals, and presumably the coal beds outcrop somewhere in the upper part of the drainage basin of the South Fork.

ROUTES AND METHODS OF TRAVELING.

The conditions of traveling in this region are similar to those which have so often been described elsewhere in Alaska. Probably the easiest journeys are made in winter when sledding is possible, with the use of dogs for draft animals. It is necessary to supply dog food either by carrying it along, which limits the length of the journey from the base of supplies, or by procuring dried fish, which, as a rule, can be had only at the Indian villages. Dogs are also used by the Indians in summer for carrying packs. Reindeer can probably be utilized in the uplands, where the reindeer moss is to be found. In the larger river valleys, as far as my observations go, the moss is not abundant, and the reindeer used for river trips would have to seek the uplands for food. The utility of reindeers as draft animals has been well demonstrated elsewhere in Alaska, and they have the advantage over dogs in that they find their own food. Up to the present time they have not been given a fair test as pack animals for summer use, but it seems possible that they may be better adapted for this purpose in this region than the horse or mule.

In summer supplies are transported by back-packing, by pack animals, or in boats. By the more primitive method of back-packing journeys are usually limited to three weeks, as this is the longest period for which the average man can carry provisions besides his blankets, etc.

Horses can be used to advantage from about the middle of June to the first of September. Horses are preferable to mules because of the large amount of soft ground which has to be crossed. Our experience teaches us that "sawbucks" are better than "aparejos," as the pack is less liable to slip off. In choosing a route for a pack train it is advisable to keep at as high an elevation as possible, thus to avoid the swamps and thick timber of the lowland. We found the best grass above timber line.

A party making a trip in this region which involves crossing any of the larger rivers should carry a folding boat or the equipment for

constructing one. We used a heavy, waterproofed canvas which we stretched over a framework built by the use of a few simple tools.

Not much of the region is favorable for boating. Most of the larger rivers can be descended in boats at certain times in the year. Both the White and the Tatshenshini have been run in boats built by prospectors from whipsawed lumber. The Upper Tanana below the gorge, as well as the Nabesna, are favorable for the use of small boats, as are also the large lakes.

DALTON TRAIL.¹

This trail leaves the coast at Pyramid Harbor, situated near the head of Chilkat Inlet, where the depth of water is sufficient for any seagoing vessel. In 1899 no wharf existed and freight was taken ashore by lighters.

The trail from Pyramid Harbor to Dalton House, in the interior, has been described in the itinerary. I will add that the hardest climb of the whole length of the trail is about 40 miles from the coast, near the police post. Here the crossing of a high spur necessitates a climb of 1,000 feet, which could be avoided by constructing a trail up the Klehini Valley. At Dalton House, which is about 100 miles from the coast, the trail turns northward, keeping to the east of Lake Deza-deash, and continues down the Kaskawulsh River, which drains the lake, to where this river makes its right-angled bend to the coast. It then crosses to the headwaters of Mendenhall River and thence continues to the Nordenskiöld, which it follows down to the Lewes River.² The Dalton trail proper ends at the mouth of the Nordenskiöld, but there is said to be a route all the way in to Dawson which has been followed by cattlemen with beef herds.

The exploration of this route for a trail, and its subsequent establishment, is due to the indomitable energy and perseverance of Mr. Jack Dalton. Mr. Dalton has done more than any other man for the exploration and development of this region.

The trail usually opens between the middle of June and the first of July. In the fall it can be used until about the middle of September. A permit having been granted by the Secretary of the Interior, the Alaskan portion of the trail is now a toll route. Below Pleasant Camp much money has been spent on the trail in road cutting, bridge building, etc.

ROUTES TO THE UPPER WHITE AND THE UPPER TANANA.¹

The route followed by our party to the Tanana River is entirely feasible for a pack trail. The chief obstacles are the crossing of the

¹See Pl. XL.

²Many maps show the Dalton trail leading to Fort Selkirk, and in a previous publication I fell into the same blunder. The Dawson Range intervening makes such a route impracticable for pack trains. The Indians, however, are said to have a trail across this range.

large rivers. Only in the Nabesna and Tanana valleys did we have to do much trail cutting. The following table of distances has been compiled from our map:

Table of distances along route of expedition from Pyramid Harbor to Eagle City.

	Pyramid Harbor.	Pleasant Camp.	Dalton House.	Kaskawulsh River. South end of Lake Klutane.	Donjek River.	Kletsan Creek.	Head of White River.	Tanana Glacier.	Nabesna River.	Tanana River at mouth of Tetling River.	Franklin Gulch.	Steele Creek.	Eagle City.
Pyramid Harbor.....	40	95	130	185	250	295	210	340	375	430	520	530	580
Pleasant Camp.....	40	.....	55	95	145	210	255	170	300	335	390	480	540
Dalton House.....	95	55	.....	45	90	155	200	115	245	280	335	425	485
Kaskawulsh River.....	130	95	45	.....	45	110	155	170	200	235	290	380	440
South end of Lake Klutane.....	185	145	90	45	.....	65	110	125	155	190	245	335	395
Donjek River.....	250	210	155	110	65	.....	45	60	90	125	180	260	330
Kletsan Creek.....	295	255	200	155	110	45	.....	15	45	80	135	215	285
Head of White River.....	210	170	115	170	125	60	15	.....	30	65	120	200	270
Tanana Glacier.....	340	300	245	200	155	90	45	30	.....	35	90	170	240
Nabesna River.....	375	335	280	235	190	125	80	65	35	.....	55	135	205
Tanana River at mouth of Tetling River.....	430	390	335	290	245	180	135	120	90	55	.....	80	150
Franklin Gulch.....	520	480	425	380	335	260	215	200	170	135	80	.....	70
Steele Creek.....	530	490	435	390	345	280	235	220	190	155	100	20	50
Eagle City.....	580	540	485	440	395	330	285	270	240	205	150	70	.....

A party intending to reach the Tanana or White from Eagle City would do well to take the Mentasta Pass trail from Franklin Gulch in the Fortymile Basin and reach the Tanana by way of the Khiltat. After crossing the Tanana it should make its way in a southeasterly direction and strike our trail near Tetling, or, what would probably be easier, follow the Mentasta trail to the Copper and then reach our trail on the Nabesna by the Batzulnetas trail. By this latter route it would be about 225 miles from Eagle City to the Nabesna. From Fort Selkirk the overland route, which is said to be an old Indian trail, used by Schwatka and Hayes, is passable for pack animals. By this route it is about 175 miles to the Klutlan Glacier, and the Donjek is the only river of considerable size which would have to be crossed. From the mouth of the Nordenskiöld, on the Lewes, a route exists to the White by way of the Nisling Valley. Mr. J. B. Tyrrell's explorations of this route have already been referred to. On the accompanying map this route is continued across the White to the Tanana. This is entirely feasible except for the crossing of the White, which would be difficult. By descending the river to near the mouth of the Klotassin the crossing could probably be accomplished. The

distance from the Nordenskiöld to the mouth of the Nisling is about 175 miles.

The shortest and probably the best route to the head of the Tanana or White is the Copper River route, which leaves the coast at Valdes, on Prince William Sound. From this point a trail is now under construction by engineers of the United States Army, which is to avoid crossing the glacier. This proposed trail is to keep east of the Valdes Glacier and reach the Copper River at Copper Center, at the mouth of the Klutena. The rivers near the coast are said to have already been bridged, and the other streams, as the Konsina, will be crossed near their headwaters and will offer no serious obstacles. As the trail reaches the Copper on the south side of the Klutena, and as the former river is usually crossed above the Klutena, the latter river will have to be crossed, which is no easy matter. It will be necessary to use boats in crossing both the Copper and the Klutena. After crossing the Copper the so-called Millard trail is followed to the mouth of the Slana; a turn to the eastward is then made to Batzulnetas, from which point a crossing can be made to the Nabesna, or across the Suslota Pass to Tetling. The distance from Valdes to the Nabesna by this route is about 200 miles.

One of the routes into the interior which was tried during the Klondike excitement of 1898 and 1899 crossed from Disenchantment Bay, which is the upper end of Yakutat Bay, to the Alsek, and thence extended up that river and its tributaries. As a route into the interior it seems to have been a lamentable failure. Over 60 miles of glacier had to be crossed to the Alsek, and when that river was reached it was found to be very turbulent and exceedingly dangerous to ascend. There was, moreover, an absence of fuel on the glacier route, and only stunted alder on the Alsek. Some 300 prospectors are said to have started inland by this route, but probably not over 20 reached Dalton House, and those only after eighteen months of the hardest kind of toil and exposure. Several deaths due to exposure or to starvation have been reported from this region.

RAILWAY ROUTES.

Should the copper deposits of the Upper White and Tanana prove to be of sufficient extent to pay for a railway to them, the Copper River route would undoubtedly be chosen. Valdes, the natural terminus of such a railway, has an excellent harbor, which is open the entire year. A high divide would have to be crossed between Valdes and the Copper River. The next difficulty would be the crossing of the Copper River. The divides between the Nabesna and Copper and the Tanana and Copper is not over 3,000 feet.

The route from Pyramid Harbor is one along which a railway could easily be built, except for the bridging of the several large rivers

which must be crossed in reaching the White. The Alsek Valley may also offer a feasible railway route, but as there is no harbor at the mouth of the river it will probably never be considered.

TIMBER.

Having had neither the time for collecting nor the means of transporting botanical specimens, I must confine myself to a few general notes on the timber. The timber of the coast region has been frequently described.¹ The trees are of good size and abundant. In the Porcupine gold district the development of the placers is more or less hampered by the abundant vegetation, the roots of the trees often striking very deep. Along Lynn Canal there is very little timber above an elevation of 3,000 feet. Between Rainy Hollow, on the upper Klehini, and the Tatshenshini River the Dalton trail is above timber line for much of the distance. North and west of Dalton House the timber line gradually decreases from about 4,500 to about 4,200 feet, varying somewhat according to local conditions. A stunted growth of willow and alder is still found above this up to an elevation of about 5,500 to 6,000 feet. According to the statement of prospectors there are no trees except alder and willow on the Alsek, the first spruce forest being reached about 15 or 20 miles above the junction of the Kaskawulsh and Tatshenshini. The larger valleys, like those of the two forks of the Alsek and of the White and Tanana, are heavily wooded. The Tanana is especially noted for its large trees, which are found up to 18 inches and 2 feet in diameter. The trees of the interior include several varieties of willow, alder, white birch, aspen, cottonwood, and spruce.² The spruce has the widest distribution of the trees valuable to the prospector.

GAME.

The large game of this region includes bear of several species, moose, caribou (woodland), mountain goats, bighorns, wolves, and wolverines. The Indians still trap mink, beaver, and some foxes, though the fur-bearing animals are becoming relatively scarce. The skins of moose and caribou are used extensively by the Indians for the manufacture of clothing and other articles. The natives also depend on these animals in a very large measure for their food supply. Some silver-gray foxes are caught, seven skins having been shown to me at Dalton House. Wolf and wolverine skins are still in use among the Indians, as are bear skins. In winter the Indians kill the bighorn extensively, for at that time the cold and the deep snow drive these animals from the mountain tops, which they frequent in summer.

¹ Those interested in this subject are referred to the botanical notes of Dr. Dawson, *op. cit.*, pp. 186-190.

² These names are used in a popular sense as they are commonly accepted in Alaska, no collections having been made for determination.

Moose and the larger bears are found, more especially along the valleys of the rivers and lakes. The bears have not been definitely determined by naturalists, but are classed by the prospectors as grizzly, silver tip, brown, and black bears.

Caribou inhabit the regions at and above timber line. They are migratory, and in some years are very abundant, while in others they are almost entirely wanting. While game is usually fairly abundant in the more inaccessible portions of this region, yet it would be unwise for a party to depend on it for their food supply. Our experience shows that in some seasons game is exceedingly difficult to find. Wild fowl are very abundant along some of the larger rivers. Ptarmigan and grouse are usually plentiful at and above timber line. Salmon ascend the larger rivers except where there are rock barriers.

CLIMATE.

The meteorological data collected by our party are of too fragmentary a character and are distributed over too wide an area to be worth publishing. Climatic records of the coast region of Alaska have long been made, and authentic data are now available in regard to the interior.

The Lynn Canal region is damp and has a comparatively mild climate. It is, however, colder than other parts of southeastern Alaska which are more directly subjected to the influence of the Japanese current. In the Chilkat Basin there is a heavy snowfall, which is usually all gone below the snow line by the 1st of July.

The interior region is much drier and colder. The snowfall is comparatively light, but by spring there is considerable accumulation. I was informed that at Dalton House most of the snow disappears early in June.

Before crossing the divide, about the 21st of June, we had considerable rainfall. Clear weather prevailed until toward the end of July. From the 1st of August until we reached Eagle City we had many rainy and cloudy days, though the aggregate rainfall was not great.

INHABITANTS.

NATIVES.

We saw very few natives during our journey, and are able, therefore, to add no new facts concerning them. Those of Lynn Canal and Yakutat Bay, which have been frequently described, belong to the Thlinkit stock, which includes most of the Indians of southeastern Alaska. Those of Lynn Canal belong to two tribes—the Chilkats and the Chilkoots. They are semicivilized and live in well-constructed houses in villages often of considerable size. They have long been known for their skill in weaving blankets and in certain

other handicrafts. I have seen very creditable pieces of silver jewelry made by these Indians. They are usually thrifty and prosperous. During the long period when they acted as middlemen between the white traders of the coast and the interior or "Stick"¹ Indians their livelihood was obtained chiefly by trade. Up to the time when the Hudson Bay Company established Fort Selkirk as a trading post, in 1847, they enjoyed a monopoly of the trade of the interior Indians. This monopoly they jealously guarded, as is shown by their raiding and burning Fort Selkirk in 1852.² Their trade with the interior Indians has almost disappeared, and they now earn a livelihood by catching salmon for the canneries, and also drive a lucrative trade in the curios which they manufacture and dispose of at good prices to the many tourists who visit southeastern Alaska every year.

The Chilkats are said to have waged a successful war with the interior Indians at a time not long distant and brought them to semi-subjugation. It is certain that the interior Indians stand in awe of those of Lynn Canal and will not visit the coast unless invited to do so by the coast Indians or unless they feel sure of the protection of white men. We saw several villages and houses of Chilkats along the river and inlet bearing the same name. Klukwan, at the mouth of the Klehini, on the Chilkat River, is their most interior settlement.

The interior Indians of the region visited by us belong to Athabaskan stock and may be divided into three geographical groups—those of the Alsek Basin, who are subjects of Canada; those of the White River Basin, who live largely in Canadian territory, and the Tanana Indians, who are on the Alaskan side of the line.

The only permanent place of habitation that we saw after leaving the coast Indians was the village of Neskatatwen, near Dalton House, and therefore in the Alsek Basin. Here the Indians seem prosperous and live in substantial houses. They make their living by hunting, trapping, and salmon fishing. Closely related to these Indians are those of the village of Hutshi, lying about 100 miles north of our route of travel. Indians from this district visited our camp on the Kaskawulsh.

Of the White River Indians we saw no permanent habitations. While we were camped near Kletsan Creek a party of Indians visited us who claimed to be from Lake Kluane, but we saw no houses on the lake. Dr. Hayes³ reported small Indian settlements on the Nisling and Kluane rivers. On the upper White we met a band of about 20 Indians, but they claimed to have come from the Copper River and were evidently out on a hunting expedition. Nandles, Tetling, and Khiltat are the most important settlements of the upper Tanana. The Indians of the upper Tanana have easy communication with

¹ This word belongs to the Chinook jargon, long used for trading purposes along the coast.

² An exploration in Yukon district and British Columbia, by Geo. M. Dawson: *Ann. Rept. Geol. Surv. Canada*, 1887-88, p. 139B.

³ *Nat. Geog. Mag.*, Vol. IV, p. 123.

those of the upper Copper River. The route which we followed to the White is said to be one much used by the Chilkats in their trading expeditions into the interior. In any event it is certain that the interior Indians were first supplied with the products of civilization by way of Lynn Canal. The Tanana Indians have been described in a previous report, already cited. We saw nothing of the Indians of the Fortymile region. Their chief village is said to be Kechumstuk, which is on the Tanana trail, near the head of the South Fork of Fortymile.

WHITES.

In the region explored by our party there were practically no white settlements except near the coast. Pyramid Harbor consists of a few houses and a canning factory. The latter in summer employs 50 or 60 white men, but in winter the place is practically abandoned. Chilkat, which lies on the other side of the inlet from Pyramid Harbor, has a deserted canning factory and a few houses, with one white family. Haines,¹ which is on the other side of the neck of land separating Chilkoot and Chilkat inlets, is a settlement of considerable size. At this place there are a mission, several stores, hotels, etc. Steamers daily make the trip to Skagway and return from this point. Many of the sound steamers running to Skagway also stop at Haines. Haines is connected with Chilkat by a good wagon road, and a ferry crosses from the latter point to Pyramid Harbor. All three of these places are United States post-offices. They depend for their development largely on the productiveness of the Porcupine gold district, which is about 30 miles inland.

After leaving the coast at Pyramid Harbor we passed several small settlements, some of which will probably have more or less permanency. At Walkerville were one or two buildings and 15 or 20 tents. Sunrise included a single log building. Porcupine City, near the mouth of Porcupine Creek, has several substantial buildings, including two stores and a sawmill. Prospectors' camps are also to be found along the entire length of the creek.

At Pleasant Camp,² which is beautifully situated on a bluff overlooking the river, are one of Dalton's trading posts and a northwest mounted-police post. The latter at the time of our visit included one officer and seven privates. A number of substantial buildings have been erected, and the site is probably one of the finest in the entire region.

Going inland along the Dalton trail we found a number of prospectors' camps in and near Rainy Hollow. These were then only temporary structures, but should the copper prove to have commercial value this will undoubtedly become an important place. Beyond

¹ This was formerly known as Haines's Mission.

² See Pl. XLI, A.

Rainy Hollow until Dalton House is reached there are no white settlements of any kind. At Dalton House is another trading post belonging to Mr. Dalton and in charge of a white man. There are also two members of the Canadian mounted police stationed there. The Indian village near at hand has already been referred to. There is said to be another trading post in charge of a white trader near Hutshi.

Between Dalton House, in the Fortymile Basin, and Franklin Gulch we saw no white settlements whatever, though the Indians told us that the United States Army had established a post at Mentasta Pass. In the Fortymile Basin there are a great many white men and several settlements of considerable size. At Franklin Gulch there are 15 or 20 substantial log cabins. Since the rush to Wade Creek, already referred to, a great many prospectors have come into this part of Fortymile Basin, and their cabins can be found in many gulches. On the lower Fortymile we passed a number of log houses, the largest settlement being at the international boundary, where there is now a United States custom office, a hotel, and a trading post.

Fortymile Post, at the mouth of the river of the same name, is a village of considerable size. The Canadian police headquarters, known as Fort Cudahy, is a short distance below, on the Yukon. Eagle City, some 50 miles below, promises to be the most important settlement on the Alaskan side of the line on the upper Yukon. The site is well chosen and is on the banks of the Yukon, just below the mouth of American Creek. The sanitary conditions are much more favorable than at most of the mining camps on the Yukon. The various trading-post companies have put up substantial stores and warehouses, and the Government has erected large barracks for the company of soldiers now stationed there. The Nome rush of 1899 retarded the development of Eagle City very much, and, like most of the other towns on the Yukon, it for a time became almost deserted except for the Government officials and the agents of the larger trading companies.

A RECONNAISSANCE OF THE CHITINA RIVER AND
THE SKOLAI MOUNTAINS, ALASKA

BY

OSCAR ROHN

CONTENTS.

	Page.
Introduction	399
Previous exploration	400
Work of explorers	400
Work of prospectors	401
Alaska Exploring Expedition No. 2	402
Discovery of the new route	403
Object of the expedition	403
Plans and preparations	404
Itinerary	405
Valdez to the Chitina	405
Chitina to the Nizina Glacier	406
Over the Nizina and Tanana glaciers to Copper River	407
General features	408
Topography	408
Valdes and the coast mountains	408
Copper River Valley	408
Chitina River Valley	409
Nizina River	409
The coast mountains south of the Chitina River	410
Wrangell Mountains	410
Climate and seasons	412
Timber and vegetation	414
Animal life	415
Trails	415
Tonsina and Lower Copper River	415
To the Kotsina River	416
Along the Chitina River	416
Skolai Pass	417
Upper Copper River Valley	417
From the Copper to the Nabesna and Tanana	417
Pack trains	418
Geology	418
Preliminary statement	418
Valdes to the Tonsina River	419
The Kotsina section	420
From the Chitina River to Kennicott Glacier	422
The Nizina-Tanana section	425
General relations	425
Nikolai greenstone	426
Chitistone limestone	426
McCarthy Creek shales	426
Faulting and folding in Chitistone limestone and McCarthy Creek shales	427
Other rocks	427

Geology—Continued.	Page.
Basic volcanic rocks	429
Acid igneous rocks	430
Relative age and probable correlation	431
Table of provisional correlations	433
Probable structure of the area	434
General structure	435
Mineral prospects	436
Gold	436
Copper	437
Appendix	439

ILLUSTRATIONS.

	Page
PLATE LI. Outline map of Alaska	400
LII. Geologic map of the Wrangell Mountains area	404
LIII. Summit of the Nizina-Tanana Glacier, looking west	406
LIV. Summit of the Nizina-Tanana Glacier, looking east	408
LV. Foot of the Tanana Glacier	410
LVI. Crevasses in the Tanana Glacier	412
LVII. Mountains south of Kennicott Pass	424
LVIII. View of Kennicott Glacier	426
LIX. <i>A</i> , Folding in Chitstone limestone; <i>B</i> , Amphitheater form of erosion	428

A RECONNAISSANCE OF THE CHITINA RIVER AND THE SKOLAI MOUNTAINS, ALASKA.

By OSCAR ROHN.

INTRODUCTION.

The following report is based upon field work done by me during the season of 1899, while I was in charge of a detachment of the Copper River Military Exploring Expedition. This expedition, sent out by direction of Assistant Secretary of War G. D. Meiklejohn, was commanded by Capt. W. R. Abercrombie, Second United States Infantry. The object of the subexpedition in my charge was to explore, for the War Department, the unknown area south and east of the Wrangell Mountains, and this report is prepared for the United States Geological Survey by permission of the Assistant Secretary of War, to supplement an earlier and less complete report to the War Department.

I wish to acknowledge my indebtedness to the Director of the Geological Survey for the opportunity to make this report, and to the Assistant Secretary of War for permission to do so. I am also particularly indebted to Professor Van Hise, to Mr. Willis, and to Mr. Spurr for aid in preparing the manuscript, and to Mr. Goode and Mr. Peters for help in preparing maps. Special recognition is here due to Mr. Arthur H. McNeer, the young man who consented to continue with me over the Nizina Glacier when the members of the party were unwilling to do so, and to whom I am, therefore, indebted for not having to abandon the trip at the foot of the Nizina Glacier.

The area covered by this report is attracting attention on account of the fact that it affords an opportunity for reaching the interior of Alaska from a good port by a route entirely on American soil, and because it gives promise of containing mineral wealth. The route from Valdes to the interior is indicated in red on the general map of Alaska (Pl. LI) which accompanies this report. On this is also indicated the area included in the detailed map (Pl. LII).

PREVIOUS EXPLORATION.

WORK OF EXPLORERS.

Prince William Sound, formerly known as Chugach Gulf, was discovered by Captain Cook in 1778. Soon afterwards it was visited by a number of English, Spanish, and Russian explorers, among whom were Fidalgo, Vancouver, Quadra, and Nagaief. Copper River was first seen by Nagaief in 1781, and first ascended for a short distance by Bazanof in 1803.¹ The exploration of the stream was next undertaken by a party of the Russian-American Company, who in 1843 ascended it for a short distance for the purpose of trading with the natives,² and five years later Serebrennikof, with a party of Russian explorers, succeeded in reaching a point above the mouth of the Tazlina River, where, however, he and his entire party were massacred by the natives.³ Nothing was done from this time until 1882, when C. G. Holt, a trader in the employ of the Alaska Commercial Company, reached Taral. Two years later Captain Abercrombie, of the United States Army, made an effort to ascend the river, but did not succeed in getting farther than Miles Glacier.⁴

In 1885, the year following Captain Abercrombie's attempt to ascend the river, Lieut. Henry T. Allen, of the United States Army, made one of the most remarkable exploration trips recorded in Alaskan history.⁵ He ascended the Copper to Taral. From here he reached the Nikolai house, on the Chitina, by portage, and returned down the Chitina by boat. He then made his way up the Copper to Batzulnetas. And from here, crossing the Mentasta Mountains to the Tanana River by way of Suslota Pass, he descended the river to the Yukon. Though he and his party practically lived off the country and suffered great privations and hardships, he was not content with his great success, but ascended the Koyukuk for a distance of several hundred miles before returning home by way of the Yukon and St. Michael.

To Lieutenant Allen we are indebted for the first reliable maps and information regarding the Copper, Chitina, and Tanana rivers, and the group of mountains surrounding the active volcano known as Mount Wrangell. In 1898 a party of the United States Geological Survey, in charge of Mr. W. J. Peters, accompanied by Mr. A. H. Brooks as geologist,⁶ explored and mapped the Tanana River from a point where it leaves the mountains to its confluence with the Yukon.

In 1891 Lieut. Frederick Schwatka and Dr. C. Willard Hayes⁷

¹ Alaska and its Resources, by W. H. Dall, pp. 317-321.

² Bancroft's History of Alaska, p. 526.

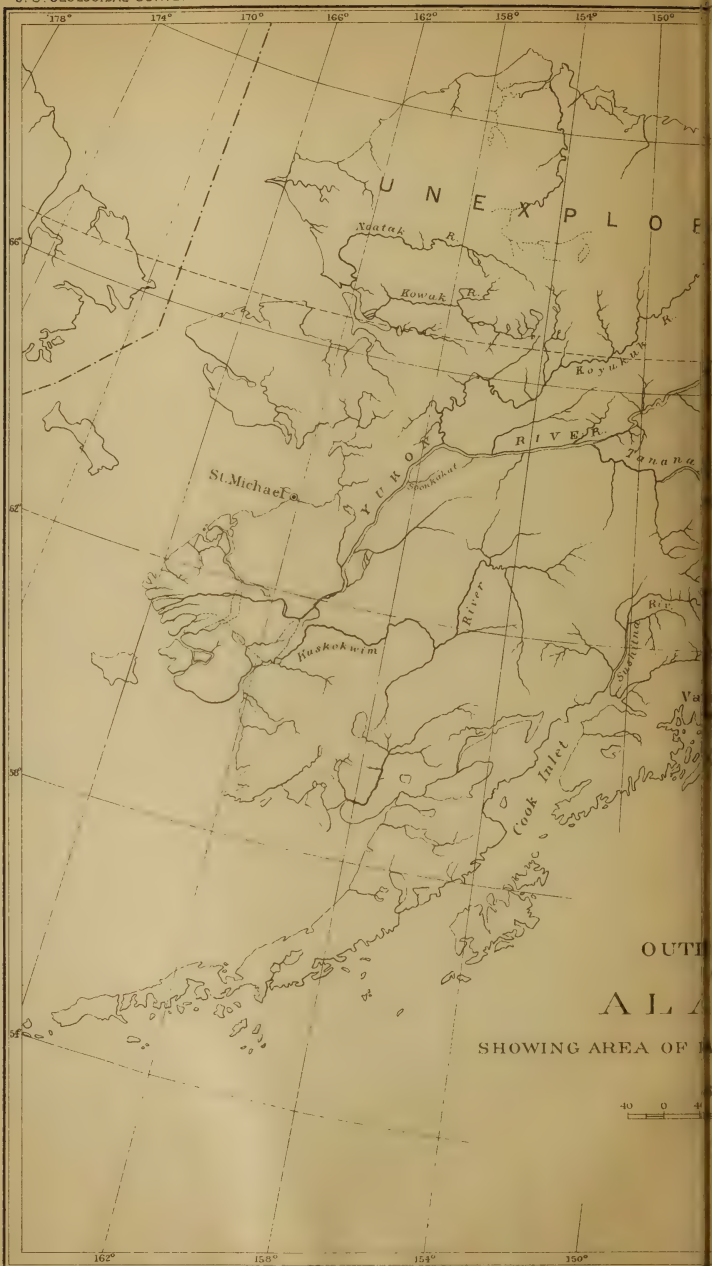
³ Alaska and its Resources, by W. H. Dall, p. 272.

⁴ Reconnaissance in Alaska, Lieut. H. T. Allen, 1885, p. 23.

⁵ Op. cit.

⁶ Explorations in Alaska in 1898; U. S. Geol. Survey, p. 64.

⁷ An expedition through the Yukon district, by C. W. Hayes; Nat. Geog. Mag., May 15, 1892, Vol. IV p. 120-127.

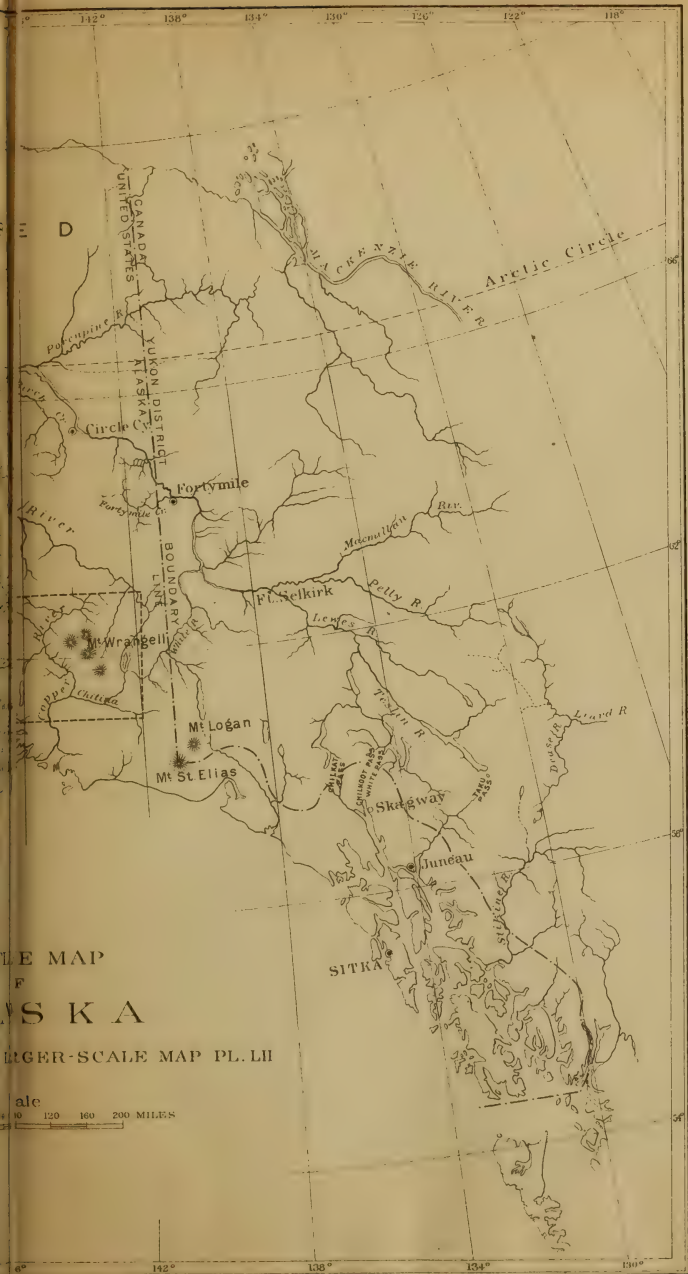


OUTLINE

ALASKA

SHOWING AREA OF





entered the Chitina Valley through the headwaters of the White River, by way of the Skolai Pass, which they discovered and named. Reaching the headwaters of the Nizina River, they built a boat in which they ran down the Nizina to the Chitina, then down the Chitina to the Copper, and along this to the coast. Considering the difficulties which both Lieutenant Allen and Dr. Hayes encountered, their maps and observations are remarkably accurate, though they are, of course, restricted to the immediate vicinity of the respective routes traveled.

WORK OF PROSPECTORS.

The general rush to Alaska in the spring of 1898, due to the Klondike discoveries of the previous year, resulted in the landing of between 4,000 and 5,000 prospectors with their outfits at the head of Valdes Bay during the months of March, April, and May of that year. A route was supposed to exist from here to a point on the Copper River above the rapids and canyons reported by Lieutenant Allen, but no exploration of this route had ever been recorded, and no information regarding it could be obtained.

The general impression among these adventurers, that the interior was a great field of treasure and that beyond reaching it little else was needed to enable them to gather a fortune, spurred them into attempting to cross the glacier that occupies the only break in the mountains surrounding Valdes which seemed to give promise of leading from the bay into the interior. This, subsequent developments proved it to do, but the difficulties which it presented were very great. With the thermometer at 40° to 50° below zero, in the fierce storms which only polar glaciers can give birth to, and with fuel at \$1 a pound, outfits were sledged over a course that in places required hoisting by means of rope and tackle.

Beyond this glacier, which is now known as the Valdes Glacier, a swift and powerful stream, which proved to be that named by Lieutenant Allen the Klutena, was found to lead in a general northeasterly direction to the Copper River, and by carrying their goods down this in boats the more fortunate reached Copper River. Many of those who reached Valdes never landed; many more turned back disheartened at the glacier; others succeeded in crossing the glacier only to lose their outfits in the swift and treacherous waters of the Klutena, and only a minor part of the crowd that landed ever got far beyond the mouth of the Klutena, where a winter camp sprung up which was called Copper Center. Nearly all of those who went beyond Copper Center were headed for the Yukon by way of the Mentasta Pass and the Fortymile River. Mentasta Pass was reached by two general routes—one by "tracking" or "cordelling" boats up the Copper River, the other by an overland route leading from Copper Center

along the foot of Mount Drum to the mouth of the Slana, known as the Millard trail. At the mouth of the Slana the two routes converged and, following along the eastern bank of this stream, led to Mentasta Pass. A number of parties made this trip and the routes were well established. One party even made the trip to the Yukon and return in the course of the season.

The major portion of each man's time was spent in traveling and transporting goods, and, considering the number of men who reached the interior, comparatively little prospecting was done. Such as was done was confined to the immediate vicinity of the routes named and to the Copper River from Copper Center to the coast. The short streams tributary to the Copper heading in the Wrangell Mountains were explored to some extent, but the Chitina was ascended only a very short distance. All of the mineral prospects discovered by the season's work were practically confined to those of Quartz Creek, a southern tributary of the Tonsina. This was discovered in August, but was not reported until later in the season, when a general stampede for the area occurred.

The discouraging prospects led many to leave the country at the approach of winter. Some returned over the glacier to Valdes, but more went down the Copper River to the coast in boats. Of those who had sufficient provisions and were determined to explore farther the greater number wintered at Copper Center, at Quartz Creek, and at Valdes. A few were scattered in isolated camps along the Klutena and along the Copper River below Copper Center.

ALASKA EXPLORING EXPEDITION NO. 2.

The War Department, in an endeavor to find an all-American route to the interior of Alaska, put three parties in the field in the spring of 1898; one at Cook Inlet, one at Prince William Sound, and a third at Lynn Canal. The Prince William Sound expedition was in charge of Capt. W. R. Abercrombie, United States Army. It landed at Valdes in April, and spent the earlier part of the season examining the coast of Prince William Sound and the different bays or fjords adjacent to it. In August a start was made for the interior. A detachment of the expedition in charge of Mr. F. C. Schrader,¹ a member of the United States Geological Survey, detailed with the expedition, crossed the glacier with a pack train and reached Copper Center by the then well-established trail along the Klutena River. Here the party divided, one detachment, under Lieutenant Lowe, going northward to Mentasta Pass and finally reaching Fortymile; and the other, in charge of Mr. Schrader, going down the Copper River. Taral was reached with the horses. These were then abandoned and

¹ A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, by F. C. Schrader: Twentieth Annual Rept. U. S. Geol. Survey, Pt. VII, pp. 321-423.

the journey was continued by boat to the mouth of the Tasnuna. From here, by back-packing up the valley of the Tasnuna, Mr. Schrader succeeded in reaching the valley of the Lowe River, and along this he made his way back to Valdes.

The year's work showed that beyond the coast mountains the country is open and affords splendid opportunities for the construction of pack trails and railroads; but that, unless a way of avoiding all glaciers could be found through the coast mountains, a general route from Valdes to the interior was not feasible.

DISCOVERY OF THE NEW ROUTE.

The finding of placer prospects attracted prospectors from the Klutena River to Quartz Creek. From here they worked over a low divide into the valley of the Kanata. Finding a few colors of gold in the gravels of this, they followed it to its confluence with the Chena, and worked up along the banks of the latter for a distance of 12 to 15 miles. The route from this point to Valdes being very circuitous, a man named Johnson who, with a companion, made monthly trips with the mail from Valdes to the various camps, attempted to find a more direct one. He made several attempts to find his way from the Chena out to Valdes, in one of which his companion perished from freezing. Johnson, however, persevered and finally succeeded in reaching the Lowe River Valley by way of what is now called the Lowe River divide. This was the final step that completed the all-important route through the coast mountains and made possible what now promises to be the gateway to the interior.

When Captain Abercrombie's expedition landed in the spring of 1899, Johnson's discovery had become generally known, and several parties of prospectors who had landed early in the season were already at the summit of Lowe River divide, bound for Quartz Creek with their season's supplies.

OBJECT OF THE EXPEDITION.

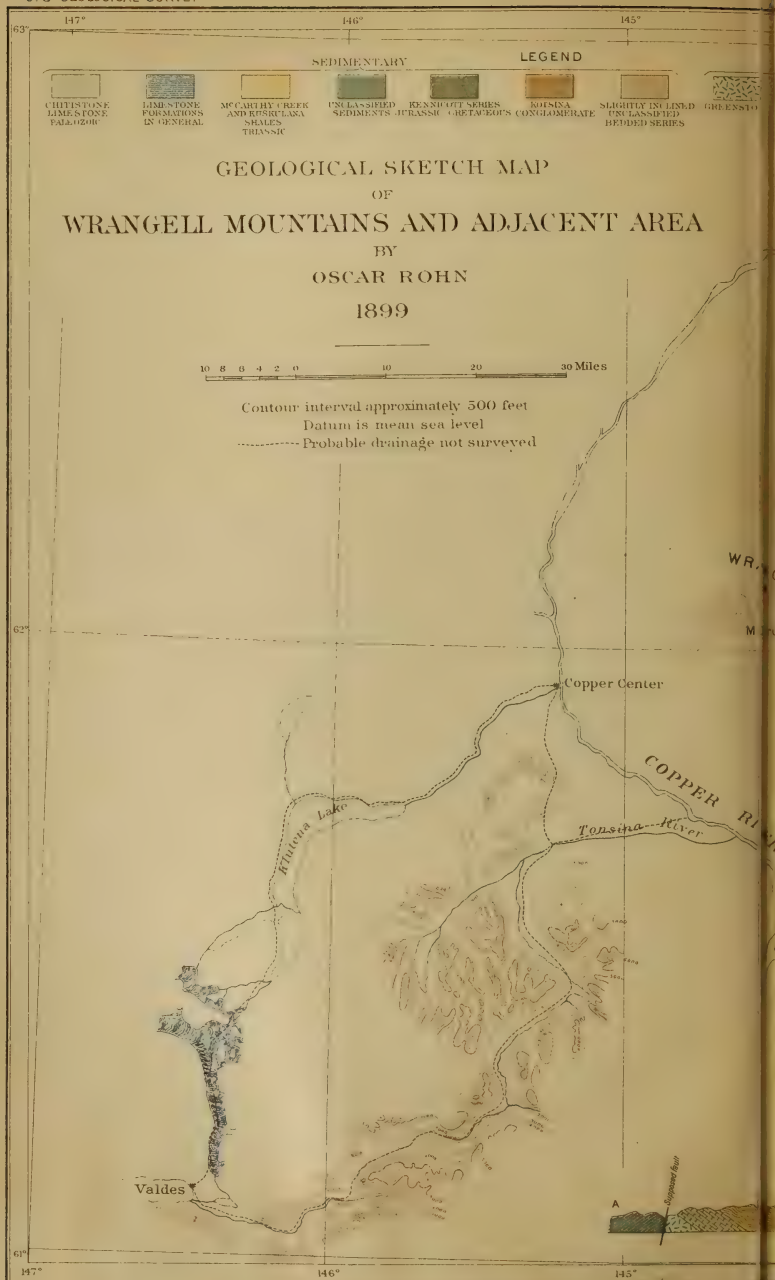
No satisfactory placer prospects having been found in 1898, the mountainous region east of Copper River attracted the attention of those prospectors who remained through the winter, as affording the most favorable field for further work. Copper deposits were known to exist somewhere in this area by the fact that the natives repeatedly brought specimens of this metal to the trading stations on both the coast and the Yukon, and to these deposits the attention of prospectors was drawn by the opening of copper claims on Prince William Sound during the previous year. The explorations of Lieutenant Allen and Dr. Hayes showed that the area is exceedingly rugged and difficult of access, and that it forms the divides between four great streams. But

beyond this nothing was known of it. Under these conditions it was most important to the work of the prospectors and the development of the area, and of much interest from a geographic and scientific standpoint, that the area should be explored and mapped, and its true nature and accessibility be determined. To undertake this work, a detachment of the expedition was detailed by Captain Abercrombie and put in my charge. The plan decided upon was to work up the valley of the Chitina with a pack train, and, if possible, to cross to the headwaters of the Copper. If it was found impossible to proceed with the horses, they were to be left, the trip to be continued by back-packing or sledding. Upon reaching navigable waters on the Copper River it was intended to build rafts or canoes, and by means of these to run down Copper River to Copper Center.

PLANS AND PREPARATIONS.

The general experience of Alaskan explorers has shown that, as a rule, each member of a party must carry his own provisions, and that increasing the number of men in a party is merely increasing the amount of provisions necessary and adding to the difficulties. The area to be explored was known to be very rugged and forbidding, and one in which back-packing would probably have to be resorted to. It was therefore decided to select instruments for cartographic work and the necessary provisions and camp outfit with a view to the least weight and bulk that could possibly be made to serve the purpose. The party was accordingly restricted to four men. I was to take charge of both cartographic and scientific work; two packers, J. V. Place and H. H. Fitch, were to handle the pack train, and John Fohlin was to act as cook and camp man. The instrumental outfit for cartographic work consisted of a Johnson's improved traverse plane table with a small open-sight alidade, a small sextant with an artificial mirror horizon, an aneroid barometer, and two high-grade watches. In addition to a very light camp outfit, two 11-foot canvas folding canoes were carried to provide for crossing glacial streams. It was found that these were too small and that one larger boat would have been more serviceable. No provision was made for crossing glaciers, but fortunately we were able to secure two sleds at the Nikolai House.

Not being provided with the fuel and cooking arrangements ordinarily used in glacial work, we prepared as much bread and bacon as possible before starting over the glacier, and carried with us dry spruce timber with which to prepare a little coffee and oatmeal daily. Though this arrangement sufficed to carry us through, it did not fail to show us the inadvisability of undertaking an extended and uncertain glacial trip without suitable and adequate provision for preparing food on the way. It is, however, almost equally undesirable to carry coal oil and lamp stoves on a long overland trip when there is only a possibility



144°

143°

142°

IGNEOUS

-  VOLCANICS
andesitic, basaltic, and
trachytic
-  INTERSEVEN
GRANITE
MASSSES
-  METAFOLIO
LIMBIC L.W.S.
COMPARATIVELY RECENT



Section on the line A - B

SKOLAI MOUNTAINS

PRESUMABLY VOLCANICS
AND SEDIMENTARIES INTERBEDDED

NUTZOTIN MOUNTAINS B

144°

143°

142°



that there will be occasion to use them. This can be avoided by providing a small folding sheet-iron charcoal pot. Charcoal being very light, sufficient for a considerable time in an ice or timberless area could be carried, and this could be readily prepared at the point of beginning such part of the trip.

ITINERARY.

The new route to the interior, as has been explained, had been discovered and its practicability determined when Captain Abercrombie landed with his expedition in the spring of 1899. He therefore directed his attention at once to building a trail through Keystone Canyon, on Lowe River, about 12 miles above its mouth. The prospecting parties mentioned as having gone in earlier in the season had passed through the canyon on the ice. It was now, however, too late to do this, and the necessity of building a trail around the canyon delayed our start until the 18th of June. In the meantime the area about Valdes and the shore of the bay were carefully examined and mapped in detail, and a series of soundings were made in the bay.

VALDES TO THE CHITINA.¹

In company with a detachment of the Copper River Exploring Expedition conveying the United States mail inspector from Valdes to Eagle City, on the Yukon, and the United States mail contractor and several parties of prospectors, we left Valdes on the 18th of June. The first day's route lay along the north bank of Lowe River to Keystone Canyon. This, a deep, rocky gorge by which Lowe River breaks through the mountains, was passed by way of the new trail, just built. Beyond Keystone Canyon the course lay up the north side of the Upper Lowe River Valley, a distance of about 7 miles, to Lowe River divide, which was crossed at an altitude of 2,600 feet. From here a journey of about 7 miles in a general northeasterly direction took us to the Chena River. Thus far we had traveled over a trail prepared by prospectors who, as has been said, came in earlier in the season. These we found encamped at the head of the Chena River awaiting our arrival, and from here on it became necessary to pick and prepare a trail suitable for further progress. In this I was assisted by Mr. R. F. McClellan, who was in charge of a large prospecting party.

After following the valley of the Chena as best we could for a distance of about 15 miles to its confluence with the Kanata, we proceeded up the right bank of the latter stream, and by way of a divide known as the "Drop" we reached Quartz Creek, which we followed to its mouth at the foot of Tonsina Lake. From here part of the outfit was taken to Copper Center by way of the Klutena River, arrangements being made to have it brought down Copper River by boat. While this was being done, the trail leading from Tonsina Lake to the Copper

¹ This name has been spelled in various ways. For Alaskan names see pp. 187-509 of this report.

River was cut out and marked, so that by way of it the pack train could be taken to Copper River on its return to Tonsina Lake. Copper River was crossed a little above the mouth of the Tonsina. From here the outfit was carried to the mouth of the Chitina in boats, and the horses were driven down the river along the eastern bank.

While the relay trips of the pack train necessary to bring the outfit to the Copper River were being made, a side trip of ten days was made up the Kotsina River by way of the trail from Copper River.

CHITINA TO THE NIZINA GLACIER.

From the mouth of the Chitina, which we reached on July 21, we followed an old Indian trail leading along the northern side of the river. This trail was very old and very little used, but having secured an Indian guide acquainted with it, we had no difficulty in following it. It led us directly to the mountains, and up into these along the western bank of the Kuskulana River for a distance of 5 or 6 miles. Then crossing the river near the foot of the glacier, we entered a narrow, transverse gulch leading away from it into the mountains eastward. After rising rather steeply for some time, this gulch opened out into a broad valley, which we followed in a general southeasterly direction for about 15 miles. Here we encountered the second stream of considerable size, known as the Lachina. The Indian trail leads off southward at this point, and we decided to abandon it and attempt to continue through a narrow valley leading eastward through the mountains. This valley, which is transverse to the general drainage of the area, was found to lead out upon a large glacier for which I propose the name of Kennicott Glacier.¹ This glacier being too rough to cross with the pack train, it was necessary to work around the foot of it for a distance of about 8 or 10 miles. Beyond this the valley of a small stream opening into the glacial valley enabled us to continue in a general northeasterly direction, and finally, after crossing a mountain range at an altitude of 6,500 feet and after descending 4,000 feet on a very steep and difficult slope, we succeeded in reaching the valley of the Nizina River.

We were traveling along the southern side of a very high range of mountains extending eastward from Mount Blackburn. We had thus far been unable to find any opportunity to cross. On the Nizina, however, we found the lowest divide yet seen, and, while it was occupied by a large glacier, it seemed to offer the only opportunity of crossing, and we decided to attempt to cross here. We continued up the valley of the Nizina to a point about 3 miles above the foot of the glacier. Dr. Hayes,² who first saw this glacier, regards the Nizina

¹ Named in honor of Robert Kennicott, a pioneer in Alaskan exploration, who, as director of the scientific corps of the Western Union Telegraph Expedition in 1865, established the identity of the Kwikpak of the Russians and the Yukon of the English, and who sacrificed his life in the undertaking.

² Op. cit.



SUMMIT OF THE NIZINA-TANANA GLACIER, LOOKING WEST.

River as heading in Russell Glacier and crowded out of its course by this, which he calls a great triple glacier. It will be referred to as the Nizina Glacier.

OVER THE NIZINA AND TANANA GLACIERS TO COPPER RIVER.

Finding it impossible to proceed farther with the horses, the party was divided, I and Mr. A. H. McNeer¹ continuing over the glacier, while the remainder of the party returned to Valdes with the pack train.

The glacier would be difficult to cross at any time, but at this season of the year it was especially so. By exercising all possible care and awaiting our opportunity, we succeeded in making our way over the summit, and at the end of fifteen days reached the foot, on the opposite side. The summit was found to be over 8,000 feet above the sea, and the length of the glacier from foot to foot along the route which we traveled was about 47 miles.

During the trip over the glacier the storms which are almost constant on the summit at that time of the year, the difficulties of traversing glacial ice, and snow-blindness absorbed our attention and left us no time to speculate on what drainage we were reaching. When, however, the glacier had been crossed, the latter became the all-absorbing question. After following the stream which headed in the glacier for a distance of 12 or 15 miles in a northeasterly direction, and finding that it led out of the mountains in a direction almost due east, we became convinced that it was the Tanana River, and we decided to make a portage through a gap in the mountains to the west, by which we hoped to reach what we felt sure was a branch of Copper River. At the end of a seven-days' packing trip we reached a large river, which, however, proved to be merely a branch of the Tanana, called by the natives Nabesna.

The lower Nabesna and its confluence with the Tanana are indicated on Mr. Peters's map of 1898. But it is here shown to head on the eastern side of the range, which we found it to break through.

On the mountain at the foot of the Tanana Glacier we found two stone cairns, and on the river bottoms some miles below we found horse tracks. At the time, we supposed these to have been left by prospecting parties who had started for this area in the spring with pack trains. Since returning, however, we find that the cairns are monuments left by the Peters party of the United States Geological Survey, who passed through this valley some weeks before us. We followed the tracks of this party through the pass to the Nabesna and found them to lead down the banks of this stream. We find also that a prospecting party in charge of Mr. Cooper went through the pass

¹ McNeer was a member of a prospecting party which followed the expedition, and was engaged for this part of the work on account of the difficulty of getting any of the regular members of the party to undertake it.

from the Nabesna to the Tanana earlier in the season, on its way from Copper Center to the Upper Yukon.

The season being so far advanced that ice was rapidly forming in the streams, and our provisions being reduced to less than ten days' rations, we decided to build rafts and make our way down the Nabesna and Tanana with all possible haste. Before proceeding down the Nabesna very far, however, we met natives, from whom we learned that a portage of five or six days led to the headwaters of the Copper River. Securing these natives as guides and packers, we made our way overland to Batzulnetas, on Copper River, which was reached on the 2d day of October. After rafting down Copper River for some miles we found a boat on the bank. Launching this, we made our way to the mouth of the Chislechina, where we delayed for three days in order to make a side trip for some distance up this stream. We then continued down Copper River to Copper Center, which was reached on the night of October 10. After a delay of some days at Copper Center, we proceeded in a direction almost due south for a distance of 20 miles to the Tonsina River, and from here, by way of the new military road, we reached Valdes on the 27th of October.

GENERAL FEATURES.

TOPOGRAPHY.

Valdes and the coast mountains.—The country about Valdes consists of a series of rugged, sawtooth ranges, with a general east-and-west axis, separated by narrow valleys. A partial submergence of this area gave rise to a series of deep, narrow bays or fjords, bordering the coast of Prince William Sound. The northernmost of these is Port Valdes. The trans-Alaskan military road from Valdes to the interior crosses three of these ranges—the first by way of Keystone Canyon, a deep, perpendicular-walled gorge, by which Lowe River breaks through the range; the second by a pass known as the Lowe River divide; and the third by way of the transverse valley occupied by the Kanata River.

Along the coast the valleys are very deep and narrow, and the mountains are very jagged and sharp peaked, but northward, particularly beyond the Chena, the valleys become more open and the mountain outlines become less jagged and more regular and rounded. The average elevation is perhaps 6,000 feet. On the coastward side are many small glaciers and névé fields, but toward the interior border of the range these disappear entirely.

Copper River Valley.—The southern side of the Tonsina Valley marks the northern border of the Coast Range and the beginning of a wide, flat valley, composed of a great thickness of glacial gravel and silt deposits. This valley extends northward to the Mentasta Mountains and westward to the divide separating it from the Cook Inlet drain-



SUMMIT OF THE NIZINA-TANANA GLACIER, LOOKING EAST

The left of P. LIV overlaps the right of P. LIII, and forms with it a continuous view from west to east. The valley at the left of P. LIV is that of the Tanana Glacier, and the mountains to the left of P. LIV are, again, seen at the right of P. LIII. Show the peculiar jagged outlines which characterize the volcanic peaks of this area. The mountains on opposite sides of the valley (seen at the right in P. LIV) show how their northern slopes are covered with thick snowcaps, while their southern slopes are bare.

age, while on the eastern side it is bounded by the Wrangell Mountains. Through it Copper River has cut a gorge attaining at times a depth of 500 feet and a width of a mile or more. Its tributaries join it through corresponding lateral gorges. The gradient due to this cutting, added to the already high gradient of the valley, makes these streams exceedingly swift and torrential. They are further made dangerous and unfit for boating by the fact that the glacial drift of which the valley is composed contains beds of huge boulders, which are left in the river bottoms as the finer material is washed away. The bed of the Copper River is in places, notably above the mouth of the Tazlina River, full of these boulders. Copper River leaves this valley by following the border of the coast mountains for some distance south-eastward and then breaking through them in a deep, narrow valley, at the head of which is Woods Canyon.

Chitina River Valley.—Just above Woods Canyon the Copper River is joined from the east by the Chitina, a river of about equal volume. The valley of the Chitina averages in width from 20 to 40 miles, and separates the coast mountains from the Wrangell group. The lower part of the Chitina Valley is unlike the Copper River basin, in that it is not deeply buried under glacial drift, and in that the surface is composed of a series of low, rounded domes of rock with innumerable bogs and lakelets between them. The Chitina follows the southern border of this valley, and its tributaries cut across it in gulches and canyons. The valley narrows to about 35 miles above the mouth of the river. Farther on, where the Chitina is joined by the Nizina, its great northern branch, the valley again widens. This upper valley is more heavily covered by glacial deposits and is better drained, presenting the appearance characteristic of the Copper River Valley. The main or central branch of the Chitina rises about due east from its confluence with the Nizina in a very high, snow-capped range of mountains. Some distance above the mouth of the Nizina the Chitina is joined by a branch from the south called by the natives the Tana. This is said to be extremely swift and full of rapids and cataracts, and rises far south toward the coast. Between the Tana and the Chitina several large lakes are seen.

Nizina River.—For a distance of 6 or 7 miles above its mouth the Nizina flows through a rock-walled canyon in a generally southwesterly direction. Just above the canyon it is joined from the north by a swift stream draining Kennicott Glacier. From the point where it leaves the mountains to the head of the canyon, a distance of about 15 miles, it flows through a gravel gorge in a general westerly direction. From the glacier in which it heads to the point where it leaves the mountains, a distance of from 15 to 20 miles, the stream breaks up into innumerable channels, which migrate back and forth on a flood plain sometimes 2 miles wide. This is hemmed in by high, often perpendicular, rock walls.

The Nikolai house, visited by Lieutenant Allen,¹ is just east of the great bend where the river leaves the mountain. About 5 miles above this the Nizena is joined from the east by a large tributary called the Chitstone. This rises in a series of glaciers flowing down the western side of the huge mountain range eastward.

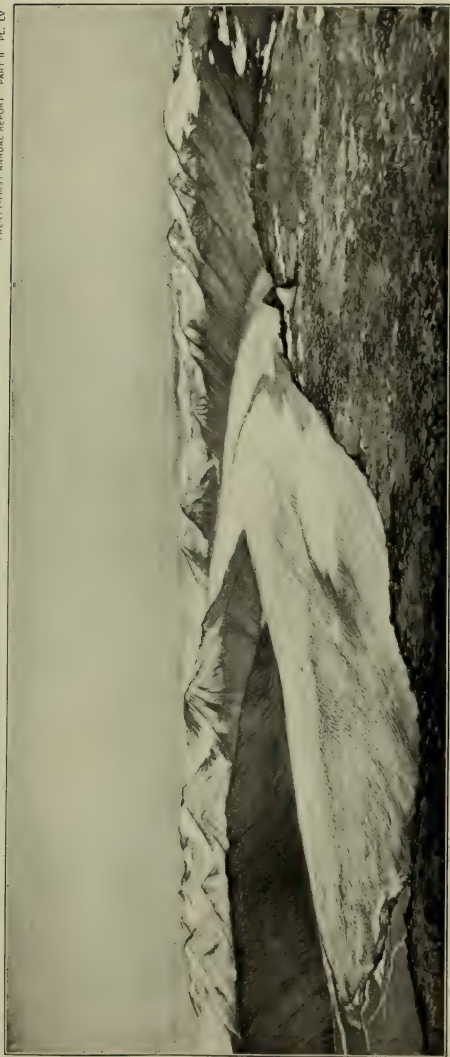
The coast mountains south of the Chitina River.—The mountains south of the Chitina, as seen from the mountains north of its valley, present the appearance of a sea of rather uniformly high, closely nested peaks, or of a plateau from 5,000 to 6,000 feet high, dissected to a depth of from 1,000 to 2,000 feet by drainage lines. It is probable, however, that this appearance is somewhat deceptive, and that in reality this area consists of a series of ranges separated by drainage lines leading in a general westerly direction toward Copper River. This is made more probable by the fact that below the Tana the Chitina is joined by no important tributary from the south.

Wrangell Mountains.—North of the Chitina Valley, occupying the great bend in Copper River, is a group of four huge, isolated peaks joined by high, impassable ranges, the whole a desolate wilderness covered by heavy snow and névé fields, the source of innumerable glaciers which extend far out into the valleys of the foothills below. The central and highest peak, Mount Wrangell, an active volcano, is a huge, smooth, rounded dome, with several small cones rising from its surface. From one of these vapor rises continually, and periodically it sends out great puffs of steam, black with ashes. About 20 miles northwest of this is Mount Drum. From its southern side Mount Drum appears very jagged, and a large part of it is cut away by erosion, presenting, as has been suggested by Schrader, an appearance of a huge crater with one side blown off.² Its northern side, however, is affected very much less by erosion, and presents a rounded outline exactly like that of Mount Sanford, farther east. Both rise majestically above all else around them and present smooth, flowing outlines that may be due to the great thickness of snow that covers them. Mount Sanford is nowhere seen cut by erosion as is Mount Drum on its southern side. High ridges connect Mount Drum and Mount Sanford with Mount Wrangell; the area between them is drained by the Sanford River, which flows northeast into the Copper River. Mounts Drum and Sanford are supposed to be between 12,000 and 13,000 feet high. The northern and western slopes of Mount Drum merge into the plains of the Copper River Valley, but Mount Sanford is surrounded toward the north and east by a wide border of rough, jagged foothills.³

¹ Reconnaissance in Alaska, by Lieut. H. T. Allen, 1885.

² A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, by F. C. Schrader: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, p. 377.

³ No mountain answering to the location and description of Mount Tillman of the older maps was seen by the writer.



FOOT OF THE TANANA GLACIER, SHOWING A PART OF THE SKOLAI RANGE.

The illustration brings out faintly a crumpling and plication in the surface moraines of the glacier at the great bend, which is strikingly like the plication of quartz veins in some of the ancient gneisses. The foot of the glacier tapers down gradually, presenting a smooth, rounded surface, almost free from moraine material.

Southeast from Mount Wrangell and some 25 to 30 miles distant from it is Mount Blackburn. This presents a rounded outline only at its very top, being cut deeply on all sides by erosion. The divide between Mount Drum and Mount Wrangell is an expanse of névé fields with isolated, jagged peaks projecting through it. This range continues with the same general character in a direction a little north of east from Mount Blackburn. Beyond Mount Regal, a peak about 25 miles from Mount Blackburn, the range is crossed by two breaks which are occupied by the Tanana-Nizina glaciers. Beyond these it turns southeastward and probably continues with the same general characteristics to its junction with the St. Elias Range.

From the foot of Mount Drum southward, bordering Mount Wrangell and Mount Blackburn, is a series of foothills, very rough and jagged in character, averaging from 5,000 to 7,000 feet in elevation, attaining around Mount Blackburn a maximum width of about 25 miles. These continue eastward as the northern border of the Chitina Valley.

The foothills east of Mount Sanford join those of Mount Wrangell and form a range with an average elevation of about 7,000 feet, which, in continuing in a northeasterly direction, joins the Mentasta Mountains and forms a divide between the Copper River Valley and that of the Nabesna. The Nabesna River is a great western branch of the Tanana, draining the entire area east of the Wrangell Mountains, which was formerly supposed to belong to the Copper River drainage. This river flows in a northeasterly direction and breaks directly through the Mentasta Range.

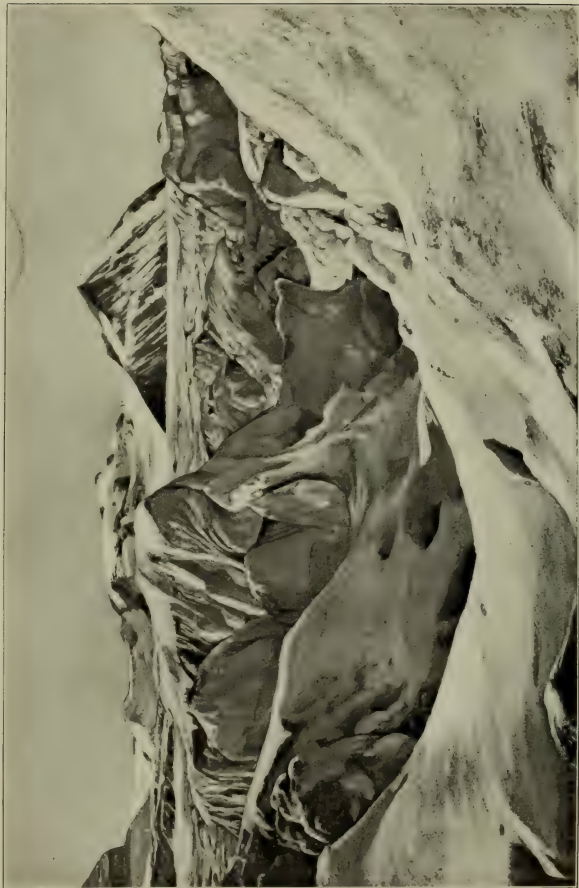
The very high Skolai Range, already described, terminates abruptly on its northern side in a depression about 20 miles wide, forming in its central portion the valley of the Upper Tanana River. Westward it contracts to a narrow pass and beyond this it forms the valley of the Upper Nabesna. To the north of this depression is a range of mountains from 7,000 to 8,000 feet high, with very jagged, irregular outlines—the Nutzotin Range¹—which is in reality a direct southern continuation of the Mentasta Range. The Mentasta Range, which extends in a general southeast-northwest direction, forms, as is well known, the divide between the Tanana and Copper rivers. Toward the northwest this range increases in ruggedness and elevation, culminating in Mount Kimball and forming a part of the Great Alaskan Range. The south side of this is drained by the Chislechina, one of the largest western branches of the Copper River. Along the Upper Chislechina and along the southern border of the Mentasta Range is a series of low, rounded foothills, and to the west nothing could be seen but a continuation of the flat plains of the Copper River Valley.

¹ A reconnaissance in the Tanana and White river basins, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, Part VII, p. 446.

CLIMATE AND SEASONS.

Climatic conditions divide the Copper River district into two distinct provinces. Prince William Sound and the seaward side of the coast mountains have, owing to the influence of the Japan current, the moderate temperature and great humidity characteristic of the coast of southeastern Alaska. The winters are mild and the summers are cool. The temperature seldom falls much below zero, and varies within narrow limits, while the precipitation is very abundant and cloudy weather the rule rather than the exception. Beyond the coast mountains the climate resembles that of the Middle Yukon basin, which is characterized by extreme cold in winter and moderate heat in summer, and by dry, bright, and clear weather. The coast mountains along the Copper River Valley are not nearly so high as the St. Elias Mountains, farther east, and do not so effectually precipitate the moisture from the warm ocean winds. The moisture which thus reaches the interior gives rise to heavy precipitation, which produces great snow fields and glaciers in the Wrangell and Skolai mountains. The south sides of these present the heaviest glaciation found anywhere in the interior of Alaska. On the southern border of these mountains a rainy season was encountered during August and early September very much like that which prevails at this time annually on the Bering Sea plains and along the Lower Yukon and Kuskokwim Rivers. The manner in which the clouds constantly hung on the flanks of the Wrangell Mountains at this season, while the Chitina Valley was bright and clear, was very noticeable. The difference in snowfall between the southern and the northern side of the Wrangell Mountains was marked, but not to be compared with that on the opposite sides of the coast ranges.

Not the climate alone, but the seasons as well, are different on opposite sides of the coast mountains. In the coastal region the heavy snow does not finally disappear until late in the very short spring, which intervenes between the long winter and the very short summer, and when it does disappear vegetation springs up with marvelous rapidity. In the interior the very much lighter snowfall disappears much more rapidly, and the summer season opens from two to three weeks earlier than on the coast. Extremely local conditions, due not only to difference in elevation but to the angle of incidence of the sun's rays, have a marked effect upon the season. This is impressive at Valdes. In the early summer, while the snow is disappearing from the flood plains and bottom lands of the valley and the conditions here are those of March in New England, the southward-facing mountain side to the north of the valley will be clothed in green to a considerable elevation, with flowers in blossom and vegetation in full foliage, while the northward-facing mountain side to the south of the valley is in the depth of winter and covered with a thick mantle of snow extending almost to tide water.



CREVASSES IN THE TANANA GLACIER.

As the length and progress of the season is of much interest to prospectors and explorers contemplating work in the interior, a few of the leading features of the season of 1899 are appended to serve as a guide.

When the Copper River Exploring Expedition landed on the 22d day of April, the tide-water plains about Valdes were covered with from 4 to 6 feet of snow, and between the 22d and 24th of April there was an additional snowfall of about 18 inches. It was thawing daily, however, and by the 15th of May the snow was rapidly disappearing from the gravel flats. By the 1st of June it was receding up the mountain sides and by the 15th of June the mountains were bare to the 4,000 or 5,000 foot level. The glacial streams draining Valdes Glacier and those tributary to Lowe River began to rise about June 10. Lowe River rose slowly from May 15 to June 15, then subsided somewhat to about July 10; then it again arose and was at its height about August 15. After this it began slowly subsiding.

We reached the Chitina River on the 15th of July, and at this time it was flooding from bank to bank and still rising. The highest water seen during the season was on July 28. When we reached the Nizina on August 20, the flooding season was past and the water had receded considerably. Up to August 1 the weather had been clear and bright, but at this time cloudy weather had set in with occasional showers, which became more and more marked and still continued when we left the Chitina Valley over the glacier to the north. The time when the snow line reached its maximum elevation was not accurately determined, but it was probably about August 10. On September 1, when we were crossing the glacier, the lower limit of snow on it was about 7,500 feet and was moving down rapidly from day to day. North of the glacier the snow line stood at 7,000 feet on September 10. The Tanana Glacier was at this time freezing up and the river issuing from it was rapidly drying. By September 18 the snow line at the head of the Tanana stood at about 6,000 feet. The weather was clear and cold, and ice was forming in the streams.

When we reached the Nabesna River on the 23d of September mush ice was running heavily in the main stream, and all the smaller channels were frozen over. On crossing the divide between the Nabesna and the Copper on September 29 the snow line extended below the 5,000-foot level; and on the divide, at an elevation of about 6,500 feet, the snow was 6 to 10 inches deep. Mush ice appeared in the Copper, at the mouth of the Slana, about September 25. When we reached Copper Center on October 10 the ice in the river was running so heavily that a boat could be managed only with the greatest difficulty. On the trip from Copper Center to Valdes, from October 18 to the 27, all small streams in the Copper River Valley were found frozen up. The Tonsina, which we crossed on the 21st, was frozen, except a narrow channel through the center. On the divide between the Tonsina

and the Kanata, at an elevation of 4,000 feet, the snow was $1\frac{1}{2}$ feet deep, and on the Lowe River divide, at an elevation of 2,600 feet, the snow was found over 3 feet deep on the 25th. The snow line reached tide water about November 1.

TIMBER AND VEGETATION.

Full descriptions of the different species of plants and animals found in the different parts of Alaska have been prepared by Dr. Dall and many other writers. These probably include most of the species found in the Copper River region, and no attempt to add to them can here be made. A few words regarding the distribution of those of economic importance, may, however, be useful.

The elevation of timber line varies considerably in different parts of the area. On the islands and coast of Prince William Sound it is about 2,000 feet. In the neighborhood of Valdes it is considerably less, while in the Chitina and Copper River basins it is between 3,000 and 3,500 feet, and on the Tanana and Upper Copper it is nearly 4,500 feet. The interior basins are well timbered except where burned over by the natives. This has been done on a very extensive scale, and a large amount of timber is annually destroyed by them. In places very fine timber is found. As a rule, however, especially at the higher altitudes, it is rather short and somewhat scrubby. The only timber of importance is spruce. Several kinds of poplar are found and the trees sometimes attain considerable size. They grow chiefly on old gravel bars and river bottoms. At higher elevations birch is occasionally found, but it is usually small and of little value. Willow and alder, usually as brush, though sometimes attaining a size that entitles them to be classed with trees, predominate along the upper margin of the timber belt.

Wherever the timber and the moss which usually covers the ground has been destroyed grass flourishes abundantly. Of this there are many different kinds, most of which are valuable for both hay and grazing, and are consequently of much economic importance in making possible the advantageous use of pack animals for transportation purposes.

Blueberries, black and red currants, cranberries, moss berries, and red salmon berries are found in great abundance. The red currant here found rivals in size and flavor the domestic currants of the States.

Among the many kinds and varieties of the most beautiful wild flowers which flourish everywhere in great abundance, probably the most conspicuous is the forget-me-not, which is found far above the timber line on the most barren mountains, often at the very edge of perpetual ice and snow.

ANIMAL LIFE.

According to the testimony of the natives and judging by the great number of antlers found, and the remains of traps or fences used by the natives for catching them, moose and caribou must have been very abundant in the country adjacent to the Wrangell Mountains. Now, however, they have either migrated elsewhere or become almost extinct, as only a very few are occasionally taken, on the northwestern border of the Copper River Valley. Bears are very numerous, but usually of the smaller brown and the black species. No indications were seen of the huge brown bears found on the Aleutian Peninsula. The animals now chiefly depended upon by the natives for food are mountain sheep and mountain goats. The sheep of the Wrangell Mountains differ considerably from those of the Rocky Mountains and differ somewhat also from the species found in the vicinity of Cook Inlet and the Upper Kuskokwim River. Hundreds of these animals were seen in flocks, at times, of as many as a dozen to twenty individuals. They are found, however, only at great heights, on craggy and inaccessible mountains and are usually most difficult to reach. Martens are trapped in considerable numbers, particularly by the Tanana natives, and beaver, though taken, seem not to be very numerous. Ground squirrels, which are so abundant in the western part of Alaska, do not seem to be very abundant here. Wolves and foxes, the latter including the black and silver-gray varieties, are taken by the natives.

Eagles and ravens are very common and are to be reckoned with in leaving fresh meat exposed anywhere away from camp. Brant, many different species of ducks, grouse, and ptarmigan are abundant and furnish the natives with important items of food.

Many different varieties of fish are found in the brooks and lakes. The salmon, however, is the one of most importance. These run up Copper River and its tributaries annually and furnish the natives with their only staple article of food. Every native has a "stick," or summer house, and salmon cache at some point along the river, where he lives during the summer season, catching and drying salmon, and to which he returns after the fall hunt, when the snow becomes too deep to travel. Salmon do not reach the Upper Tanana River, and the Tanana natives go to the Copper River to catch their year's supply. Halibut and cod are abundant in Prince William Sound and along the coast.

TRAILS.

Tonsina and Lower Copper River.—A good trail leads from Tonsina Lake eastward along the northern bank of the Tonsina River to a point on Copper River about 8 miles above the mouth of the Tonsina. This trail has been carefully marked and cut out and can easily be

found. From a point where it reaches the upper edge of the Copper River gorge it connects with an old Indian trail leading along the Copper River bluffs to a point on the Copper about a mile above the mouth of the Tonsina. Here a number of bars divide the river into several narrow channels, making crossing easy for pack animals. Care must, however, be exercised to keep the animals well up toward the head of the bars, as the lower ends are often soft and composed of quicksand.

A trail leads from Copper Center down the western side of Copper River. This is, however, very irregular and most difficult to travel. From a point on the Copper River opposite the mouth of the Tonsina an Indian trail leads along the eastern bank of the Copper River for the greater part of the distance to the mouth of the Chitina. In places, particularly near Indian houses, this is very good, and in others it is almost impassable. With comparatively little work a trail could be made which, leading back from Copper River about opposite from the Tonsina, and keeping well back from the river valley to avoid the lateral draws, would lead in a general southeasterly direction into the Chitina Valley.

To the Kotsina River.—On the eastern side of Copper River about 5 or 6 miles below the mouth of the Tonsina is the winter house of a native known as Bellum. From here a trail leaves Copper River and leading almost due east reaches the Kotsina River at the point where it emerges from the mountains, a distance of about 10 to 12 miles. From here it leads up the northern side of the Kotsina River Valley for 8 or 10 miles more. This trail is entirely feasible for pack horses, and by means of these the headwaters of the Kotsina can be reached at any time except that of the highest floods.

Along the Chitina River.—The general route up the Chitina River is the Nikolai trail, leading from Taral over the mountains on the southerly side of the river to the Nikolai house on the Nizina. This is the trail followed by Lieutenant Allen in 1885. It is not feasible for pack train. An old Indian trail was found on the northerly side of the river leaving the bank about 8 miles above its mouth and running from here to the point where the Kuskulana River emerges from the mountains, and then following the Kuskulana it crosses the same near the foot of the glacier and leads in an easterly direction to the bend in the Lachina. This route is well marked out and can be traveled by pack train at almost any time of the year. From the Lachina eastward to the Nizina a trail was cut during the summer of 1899 which leads through several mountain passes and is rather difficult to follow. This may be the best route for reaching the Nizina during the time of high water, but at any other time a much better trail could easily be made which would lead down the Lachina to the foot of the mountains and along these to the foot of the Nizina, crossing the Kennicott River at the foot of Kennicott Glacier.

It is reported that the Indians formerly reached the coast at a point between Yakutat and Kyak by traveling up the southern branch of the Chitina, known by the natives as the Tana. This route involves crossing a glacier, and is not now used by the natives.

Skolai Pass.—A trail leading from the White River to the Chitina, by way of Skolai Pass, used by the natives and followed by Lieutenant Schwatka and Dr. Hayes, leaves the Nizena Valley at a point several miles above the foot of the glacier, where a valley free from glaciers joins it from the east. From the head of this valley a low gap leads to the headwaters of the White River over the foot of a glacier which Dr. Hayes has named Russell Glacier.¹ In winter the natives travel on Skolai Creek, but in the summer time, when the Nizina is flooding, they use a trail through the mountains leading to the Chitistone, and by way of this they reach the Nikolai house. This is probably the only route feasible for crossing from the Chitina to the White or Tanana. It is said to be not very difficult for traveling with a light pack, but it is quite impassable for the use of a pack train, or for railroad, or for transporting goods by any other means.

Upper Copper River Valley.—From Copper Center northward two general trails lead toward Mentasta Pass, one along the western bank of the Copper River, and the other in a more or less direct course from Copper Center to the mouth of the Slana along the foot of Mount Drum, the latter known as the Millard trail. The former probably affords the firmer footing, while the latter avoids crossing the western tributaries of the Copper. The trail leading from the mouth of the Slana to Mentasta Pass is well marked and easily followed. From the mouth of the Chestochena a good trail leads up the river along its western bank for a distance of 60 to 75 miles. From the mouth of the Slana the trail leads along the eastern bank of the Copper for a distance of about 10 miles to Batzulnetas.

From the Copper to the Nabesna and Tanana.—From Batzulnetas a good trail leads in a general southerly direction for a distance of about 10 miles, where it forks, leading by three different passes to the Nabesna River. These are all feasible for horse trails, and each is advantageous according to the point on the Nabesna that is to be reached. The western one, by way of Lake Tanada, was used by prospecting parties traveling with pack train during the season of 1899, and the central one was used as a sled route. The eastern one, however, is the most practicable and the easiest, particularly for reaching the trail from the Nabesna to the Tanana and White rivers. The western one, which was traveled by pack trains, is well marked up, but the others are difficult to follow and require guides.

¹ An expedition through the Yukon district, by C. W. Hayes: Nat. Geog. Mag., May 15, 1892.

The trail from the Nabesna to the Tanana leads to one of two passes. The northern one, the most direct and the one used by the natives, is not feasible for pack horses, while the one a little farther south is. This is the only part of the route that offers any difficulty whatever for railroading, but the difficulties are not such that they can not be readily overcome.

PACK TRAINS.

The military road and the network of trails found in the Copper River Valley make pack trains the only convenient and satisfactory means of transporting goods; they can be used to advantage from about the 10th of June to about the 10th of October, and they have been adopted almost exclusively by the prospectors now working in the country. If large quantities of goods are to be transported, this can in some cases be done to advantage by sledding with horses on the ice of the rivers during the months of February, March, and April.

The experience of the past year's work with different outfits prompts the following suggestions: A stocky Montana ranch horse weighing about 1,200 pounds, which had not been used as a harness horse and which had not been stable fed, was found to be the most satisfactory. Such horses were bought for about \$40 and cost about an equal amount for transportation. A well-fitting double-cinch sawbuck saddle, without breeching or breastpad, with two heavy blankets under it, was found the most satisfactory. Saddlebags or panniers made of canvas well trimmed with leather are a great convenience and economy. These should be made just long and wide enough to accommodate a 50-pound sack of flour and should be in depth a little less than twice their width. They should be fitted with straps by which to hang them to the saddle horn. All goods should be packed in sacks and all forms of boxes carefully avoided. A very useful precaution is to have a couple of cans of baking powder well buried in each sack of flour. Pack covers made of strong canvas about 7 feet square are very useful, and a farrier's kit, with a sufficient supply of horseshoes finished and ready for the horses' feet, must under no circumstances be omitted. Two men can handle twelve horses without much difficulty, but to do so to advantage they should be allowed one saddle horse. Such horses as above mentioned will readily carry 200 pounds each.

GEOLOGY.

PRELIMINARY STATEMENT.

In exploration, where ignorance of the difficulties and obstacles to be met and overcome makes it necessary to proceed as rapidly as possible and to avoid every form of delay, geological observations must necessarily be brief and fragmentary. This was particularly true of the trip

on which this report is based. It was undertaken for the War Department with the primary object of doing topographic work. In addition to topographic work it was necessary to pilot a pack train through a difficult and unknown country, and later to continue by back-packing under great pressure. Therefore the geologic notes necessarily consist of general observations obtained incidentally and the specimens consist of such as could conveniently be picked up along the route. In a practically unknown area even such information as that gathered is useful as a guide to prospectors and to further work in the area. This being the case, the following report is warranted even if the work upon which it is based was very fragmentary.

VALDES TO THE TONSINA RIVER.

The rocks of the area about Valdes and along Lowe River have been examined and described by Schrader.¹ These consist of a series of interbedded quartzites, arkoses, slates, and shales, and occasionally some mica-schist. The rocks are very much faulted and folded. The strike is generally about east and west and the dip steeply north. The dip is rather uniform, and if the valleys between the ranges present a continuation of the series as represented in the bordering ranges the series must be very thick. It seems more probable, however, that these valleys represent either fault planes or the reverse limbs of folds, so that the ranges present a repetition of the series rather than a continuation of the same.

Northward along the valley of the Kanata these rocks are replaced by a series of micaceous and hornblende green schists. Whether these are of sedimentary or of igneous origin could not be determined. They are very much metamorphosed and closely laminated and plicated, and the series as a whole is closely folded. The effect of this change in the nature of the rock upon the topography is very marked. The jagged aspect characteristic of the Valdes series entirely disappears and is replaced by rounded and irregular outlines. No general strike and dip could be made out.

At the head of Quartz Creek these schistose rocks give way to a series of quartzites, shales, slates, and limestones. The latter series has suffered much deformation, but the accommodation has been largely by fracture and faulting, and the filling by underground circulation of the openings thus formed has given rise to a series of calcitic and quartzitic veinlets, which are so numerous that they make up a very considerable part of the rock. The contact between this series and the schistose rock southward was not seen. Various forms of acid intrusive dike rocks are common in this series, and northward become more abundant.

¹ A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, by F. C. Schrader: Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, pp. 341-423.

On the divide bordering the Tonsina Valley on the south were found the first traces of the great gravel deposits which characterize the Copper River Valley and the river valleys of the interior of Alaska generally.

Northward from the Tonsina and between it and the Klutena is a group of irregular rounded mountains 3,000 to 4,000 feet high, which, so far as examined, were found to consist mostly of volcanic rocks.

THE KOTSINA SECTION.

The Kotsina River is joined from the north by three principal tributaries. Having been unable to learn the native names for these, I will refer to them as the first, second, and third tributaries, the first being the one nearest the head of the stream, and the second and third those entering successively downstream.

At the head of the Kotsina River, a few miles west of Mount Blackburn, is found a series of bedded volcanics. The bedding in these is at times so regular and so marked that at a little distance they can hardly be regarded as of other than sedimentary origin. They are, however, basic crystalline volcanics, and resemble in a marked degree, both in appearance and in mode of occurrence, the Keweenawan diabases of Lake Superior. The main portion of each bed is massive and the edges are usually amygdaloidal. These rocks vary in color from green to brown, red, and gray. In texture they are fine-grained to aphanitic. The amygdules in the vesicular portions of the beds are usually filled with either calcite, epidote, or a green chloritic substance, and not infrequently with quartz. In the thin section these rocks are found to be composed essentially of plagioclase and pyroxene. The plagioclase is usually in the form of lath-shaped crystals with the augite filling interspaces. Olivine is usually though not always present. When present it is always more or less altered, in some cases to a green chloritic substance, in others to a reddish-brown ferrite. Pyrite, and in some cases what may be magnetite, seems to result from the alteration of the olivine. Pyrite is nearly always present in these rocks and at times is a very important constituent. All of the sections examined show the presence of some unindividualized base, and in the finer-grained aphanitic types this is at times very abundant.

The regular horizontal bedding in these rocks was observed on both sides of the river near the foot of the glacier in which it heads. In proceeding down the river this bedding becomes more and more inclined, dipping to the southwest. At a distance of about 3 miles from the foot of the glacier it disappears entirely.

The first tributary, which joins the river about 2 miles below the foot of the glacier, was followed for a distance of 4 miles to the glacier in which it heads. Throughout this distance it flows through a canyon, the perpendicular walls of which are composed of the basic

volcanics above described. In this canyon, however, they are very much cut and disturbed by both basic and acid intrusives, and in places they are very much decomposed. Near the foot of the glacier was found a mass of diabase, seemingly an irregular dike, which was so thoroughly impregnated with iron pyrite that this mineral made up a very considerable part of the rock. This dike could be traced northward along the western side of the valley by the red stain which the decomposition of the pyrite imparted to its surface. Both large and small dikes of acid volcanics were particularly numerous at this point.

The largest acid dikes are of a coarsely crystalline rock, which is composed essentially of feldspar and hornblende, and in which quartz is often present. Other smaller dikes are composed of rock probably quite similar chemically but less completely crystallized. Some of these consist practically of a groundmass containing isolated feldspar and hornblende crystals. Iron pyrite is a common impregnation in the acid as well as in the basic intrusives.

Among the moraine material found on this glacier were very fresh basaltic lavas. Some of these were highly scoriaceous and vesicular, and others compact and glassy. Two varieties of this were particularly conspicuous on account of their color—one a deep black and the other a bright red. Among these lavas were found bedded tuffs. Some parts of these are composed of very fine-grained material and others of coarse angular fragments, the whole having the appearance of being laid down under water.

About a mile below the confluence of the first tributary of the river is a mountain very conspicuous on account its smooth, regular outline. Examination showed this to be composed entirely of a granite-like rock essentially like the coarse dike rock found near the glacier on the first tributary. It is composed mainly of feldspar and hornblende, with a little quartz. The mass is seemingly an intrusive boss, and it is very probably the central mass, from which the dikes in the river to the east are offshoots. This mass is cut nearly at right angles by three series of joints, which cause it to disintegrate so readily that the sides of the mountain, from the summit to the base, are practically one talus slope. The outlines are very characteristic of these intrusive masses, a number of which are found in the mountains along the northern side of the Chitina Valley.

West of the granitic mass noted basic volcanics form the main mass of the mountains on both sides of the river for several miles. Here, however, they do not exhibit any regularity in bedding, and near the confluence of the second tributary they dip steeply under sedimentary rocks. These sedimentaries are much folded and fractured sandstones and shales, which are very much seamed by calcitic and quartzitic veinlets. The bedding is so disturbed and irregular that no general strike and dip could be made out.

Just below the confluence of the third tributary a very heavy bed of conglomerate appears, and this strikes in a direction nearly northwest to southeast, and dips southwestward at an angle of probably 30° . This conglomerate is characterized by a decidedly greenish color, which seemingly is due to material derived originally from the green volcanics. The pebbles are often very coarse and are always well rounded and waterworn. The rock is very compact and resistant, the matrix being almost as resistant to weathering as the pebbles. It is much fractured and jointed, but folding was nowhere observed in it. The appearance of this conglomerate is so characteristic that it can readily be recognized anywhere. Boulders composed of it were found in the beds of several of the streams tributary to the Chitina from the north.

West of this conglomerate the river valley widens, and here the rocks could not be examined for lack of time. The more regular features of the mountain would tend to indicate a rather flat-lying series of sedimentary rocks.

Between the foot of the mountains and the Copper River is a series of low ridges trending in a general northwest-and-southeast direction. These are composed of basic volcanic rocks and are undoubtedly intrusive dikes. They turn the course of the Kotsina River far southward before it finally breaks through them in narrow canyons.

FROM THE CHITINA RIVER TO KENNICOTT GLACIER.

Rocks are exposed in many places along the Chitina River, in some cases forming high cliffs and occasionally barriers which extend out into the river. So far as examined these rock masses were composed of a greenish-black basic volcanic, sometimes banded with streaks of lighter-colored material. The valley of the lower Chitina is a rolling, hummocky area in which small lakes and low rounded rocky ridges are very numerous. The trend of these ridges is usually east and west, and the tributaries of the Chitina from the north break through them in deep, rocky canyons. The appearance in general is that typical of a glaciated area. One of the knolls rising above the river to a height of about 1,000 feet, just west of where the Kuskulana trail leaves the bank of the Chitina, was found to be made up of a fine-grained, very dark schist, probably containing both mica and hornblende. This was cut by large dikes of basic volcanic rock. Local magnetic attraction, which was found throughout the Chitina Valley, is here particularly marked, and is due here to the presence of this schist, which was shown by the fact that a fragment of it affected the needle of the compass.

The only ledge exposed along the trail to the mountains was about 4 miles from the Chitina River. This was a light-colored, impure limestone exactly like that found later north of the pass between the Lachina and the Kennicott Glacier and again on the top of the moun-

tain east of McCarthy Creek. The exposure, however, was small, and it is not certain that the rock was here in place.

On entering the mountains along the valley of the Kuskulana, the first rocks observed were found in the bed of the first small creek joining the Kuskulana from the west. These are hard, ringing, highly silicified grits, shales, and slates, and some schists, all of which are much fractured and seamed in three or more directions by veinlets of quartz and calcite. On the second creek entering the Kuskulana from the west was found a bowlder of a dark-colored shale containing fossils which were referred by Dr. T. W. Stanton, of the United States Geological Survey, to a Triassic *Monotis*. Similar fossils were found at a number of places farther on. The dip and strike of the rock was not definitely determined. The general appearance in the distance gave the impression that they dipped southwestward with the strike nearly southeast and northwest.

Northward along the valley of the Kuskulana the outline of the mountains changes repeatedly, indicating decided differences in the nature and inclination of the rocks composing them. On either side of the pass by which we left the valley, which may be called Kuskulana Pass, are high peaks with smooth, regular outlines and few gulches, features characterizing the masses of granular igneous rock in the area. Several of these were seen farther north, and between them were jagged angular peaks showing marked bedding. This bedding is inclined sometimes in one direction and sometimes in another, and is nowhere sufficiently regular to indicate a definite strike and dip. Usually this bedding would indicate rocks of sedimentary origin. From its similarity, however, to the bedding in the volcanics at the head of the Kotsina River, but a few miles distant, it is quite possible that the rocks in which it is found here are also of volcanic origin; and the fact that the drift on the flood plain of the Kuskulana contains almost no sedimentary rock would seem to favor this view. This drift, however, is made up in large part of acid and intermediate volcanic dike rocks and contains comparatively little basic volcanic rock, which is probably due to the greater resistance of the acid rock and not to a greater abundance of the same. So also the absence of even less resistant sedimentary rock is not a potent argument that such rock is not found higher up on the stream.

On the eastern side of the granolitic peak south of Kuskulana Pass a contact was found between the granolite and an arkose or very impure sandstone. There being no conglomerate at the base of the sandstone, it is not clear whether the volcanic was intruded or the sandstone laid down upon it. The fossils collected from this sandstone were unfortunately lost on the way to Valdes. The granolite composing the mountains on either side of this pass contains considerable quartz, and the ferromagnesian mineral is almost exclusively hornblende.

The main drainage lines from the Kuskulana eastward trend approximately north and south. A second series of valleys, hardly less marked than these, trend southeast and northwest, and cut the ranges between them. These secondary valleys correspond in a general way to the strike of the rocks and probably represent a series of softer and less resistant rock or planes of weakness due to faulting or folding. One of these, a broad, open valley, begins at Kuskulana Pass and extends eastward where, as the valley of the Lower Lachina, it leads out into the valley of the Upper Chitina. The range of mountains between this and the Chitina Valley is divided by the valleys of Fitch and Dora creeks into three separate groups. These different groups present topographic outlines like those of the mountains west of the Kuskulana, of which they appear to form an eastern continuation. They probably represent the same series of shales and slates that were found along the first creeks west of the Kuskulana, and these may be conveniently referred to as the Kuskulana shales. At the western end of this transverse valley, on opposite sides of Kuskulana Pass, are the masses of granular igneous rocks that have been described. Several others similar to these were seen at various points along the valley, and a very prominent one was found just east of the Lachina. The rock composing this has a medium-grained gray groundmass, inclosing small needle-shaped phenocrysts of hornblende.

The range between the Lachina River and the Kennicott Glacier is cut by a narrow valley, which, leading out upon Kennicott Glacier, may be called Kennicott Pass. The rocks composing the mountains to the south of this are made up of shales, slates, arkoses, and probably some limestones, all much fractured and distorted and seamed by calcite veins. Reddish brown areas of interbedded volcanics are conspicuous on the northern slopes of these mountains, and intrusive dikes are numerous.

To the north of the pass, beyond a mass of granular igneous rock, the mountains are truncated and have a flat mesa top, the surface of which is an impure nodular limestone. The edge of this mesa, as exposed in the wall of an amphitheater at the head of a small valley, shows a section through a series of rather thin-bedded, light-colored sedimentary rocks dipping slightly southward.

In the bed of a small creek between Fohlin Creek and the Lachina, in Fohlin Creek, and at various points between this and the summit of Kennicott Pass, were found exposures of a light-gray, rather coarse-grained arkose, containing fossils which were recognized by Dr. Stanton as a Russian species of *Ancella*, and which were referred by him to the later Jurassic. Similar fossils were found in the small canyon just east of Kennicott Pass and again in the western lateral moraine of Kennicott Glacier. There can be little doubt that this arkose is a member of the series of the gray-bedded rocks north of the Kennicott Pass.



MOUNTAINS SOUTH OF KENNICOTT PASS.

The type of topography here illustrated characterizes the frontal ranges bordering the Chitina Valley on the north. The surface of the valley, shown in the center of the cut, has a gentle slope and at a distance appears like a mass of mud oozing out into the valley below. A closer examination shows its composition to be in no wise different from that of an ordinary talus slope. This apparent "flowage" in talus slopes was noticed in a number of places, and seems to be due to the presence of small local glaciers or patches of névé in the amphitheaters from which these talus slopes descend. They are, therefore, rather moraines than talus slopes.

The moraine on the western edge of Kennicott Glacier also contains pebbles of a dark-colored shale, in one of which was found a specimen of *Monotis* exactly like that found in the Kuskulana shales, thus indicating that these rocks occur higher up on the glacier. A light-colored brecciated acid volcanic, very heavily impregnated with iron pyrite, was very abundant in this moraine.

THE NIZINA-TANANA SECTION.

General relations.—The valley of the Kennicott Glacier represents a geological break, the rocks to the east of which are exposed in a series of parallel ridges tending approximately north and south and cutting the strike of the rocks at considerable angles. The first of these ridges is between Kennicott Glacier and Root Glacier, its eastern tributary, the second between this and McCarthy Creek, and the third between McCarthy Creek and the Nizina River.

The most conspicuous geologic feature of this area is a great limestone bed 500 feet or more thick, overlying a series of greenstones. This was first seen in a rather prominent peak at the foot of the spur between Kennicott and Root glaciers, where the contact between the two is so prominent that it may be distinctly seen in Pl. LVIII, which is from a photograph taken on a mountain west of the glacier. The limestone here dips uniformly northward at an angle of about 30° and the strike is about northwest and southeast. This general strike persists across each of the ranges eastward as far as seen. The limestone is exposed at the junction of the Nizina and Chitistone rivers, and will therefore be referred to as the Chitistone limestone. The greenstone contains the Nikolai copper vein and will be called the Nikolai greenstone.

To the south of the greenstone exposure each of the ridges is cut by a decided topographic break. This is particularly marked in the mountains east of the Nizina, where it constitutes the valley of the stream on which the Nikolai House is situated. The mountains south of these breaks in the several ranges lie in a nearly direct line with the mountains just west of Kennicott Glacier and south of Kennicott Pass. This and the fact that all of these mountains present strikingly uniform topographic features make it probable that they all represent outcrops of the same general rock series. These have been described as consisting of arkoses, shales, slates, and limestones, usually very dark in color and much fractured and seamed by calcite veins. They appear to be highly inclined, dipping southward, and are everywhere much intruded by acid volcanics, both as interbedded and as dike masses. The topography which characterizes these mountains is of the angular, jagged, sawtooth type, not unlike that of the mountains at Valdes and Lowe River, and strikingly similar to that of the Nut-zotin Mountains at the head of the Tanana River.

Nikolai greenstone.—This is a series of ancient basic volcanics. Though in general having the appearance of extrusive flows and being in some places massive and in others somewhat amygdaloidal, no regularity in bedding was anywhere observed.

In the hand specimen these rocks are characterized by a predominating green color, though at times they are somewhat reddish. Irregular spots of lighter green color are very common. In structure they are usually ophitic and in texture are coarse-grained. None of the fine-grained aphanitic phases common in the later diabases were seen. Under the microscope these rocks are found to be made up essentially of feldspar, pyroxene, olivine, some magnetite, and alteration products. The feldspar is often present in large phenocrysts, several of which are usually associated in an irregular aggregate, and these cause the spots or mottlings of lighter material noted in the hand specimen. The feldspars are generally lath-shaped, and are always much saussuritized. The pyroxene fills the interspaces between the feldspars and incloses small individuals of olivine, which are sometimes well crystallized and very abundant. The olivine is always more or less altered. In its first stages it is merely crossed by rifts and bands of a reddish-brown decomposition product, and in its final stage there is nothing left but the outline to indicate its presence.

Chitstone Limestone.—This consists of a massive bed of limestone 500 or more feet thick. It weathers gray, but on the fresh surface is of a uniform dark chocolate-brown color. In texture it is exceedingly dense and aphanitic, resembling in this respect a quartzite. While usually massive it is often brecciated, in which case the fractures are filled by coarsely crystalline calcite veins. None of this rock containing fossils was found in place. In the thin section this rock is found to be made up of rounded areas of exceedingly fine-grained material surrounded by material of the same kind, somewhat more coarsely crystalline. Sometimes areas of the finer and coarser material are arranged in concentric circles, or a ring of the finer grained material will surround an area of the coarser. Sometimes these areas are linked together in a manner strongly suggestive of organic remains.

The contact between this limestone and the underlying greenstone was examined in only one or two places, and where examined it was sharp and no traces of any conglomerate or fragmental rocks were found. The examination was not, however, sufficiently extensive to be conclusive on this point.

McCarthy Creek shales.—Overlying the limestone formation and extending northward for a distance of 6 or 8 miles is a series of soft, black, highly fissile shales and slates. These are typically exposed on McCarthy Creek and may be called the McCarthy Creek



VIEW OF KENNICOTT GLACIER

The glacier cuts across the foot of a lateral valley facing it, with an ice wall in places several hundred feet high. In the mountain between the main glacier and its eastern tributary the contact between the Nikolai greenstone and the overlying Chertstone limestone is very marked, and it may be distinctly traced in the mountain to the east. It is in this greenstone near the contact that the Nikolai copper vein is found, just west of the Nizina River.

shales. The contact between this series and the underlying limestone was nowhere carefully examined. In the Nizina exposure, however, it was sufficiently sharp and distinct to be readily seen at a distance.

Faulting and folding in Chitistone limestone and McCarthy Creek shales.—The Chitistone limestone, where first seen in the spur between Kennicott and Root glaciers and in the ridge between Kennicott Glacier and McCarthy Creek, presents a uniform dip northward of about 30°. In the eastern wall of McCarthy Creek, however, the dip of the limestone is less, and in the range to the east of this the contact between it and the greenstone is very irregular, suggesting marked displacement, principally by faulting.

Owing to the flattening of the dip and the deformation of the bed its most extensive exposure is found on the Nizina River. Here it forms vertical cliffs in the western wall of the canyon for a distance of several miles. These cliffs are in places 2,000 feet high. The great thickness of the bed is here due to marked faulting, folding, and buckling. Deformation has evidently been due to lateral compression, and the development of thrust faults from overfolds is beautifully illustrated, and has already been described by Dr. Hayes.¹ The massive bed of limestone is bent into a short overfold which is sheered off smoothly along the reverse limb and one part thrust far over upon the other (see Pl. LIX, A). Other faults have been developed with little or no preliminary folding. The faulting of the limestone is in some cases seen to extend directly into the underlying greenstone.

Eastward from the Nizina Canyon the contact between the limestone and the greenstone is found in the mountain just south of the Chitistone. Here the limestone dips northward, but in the mountain north of the Chitistone the limestone bed dips southward and forms a capping on a flat-topped mountain. It here ends northward in a precipitous bluff which forms the south wall of a lateral gulch, and beyond this the limestone appears at a much lower level, dipping gently northward under the overlying shales.

In the soft McCarthy Creek shales overlying the Nizina limestone the accommodation to deformation has been largely by flowage and has given rise to profound folding and plication and well-developed slaty cleavage and fissility. This has obscured the original bedding and made it difficult to determine the inclination of the original strata and the thickness of the series. The perfect cleavage and fissility in these shales causes them to disintegrate very readily, and this gives to the mountains smooth pyramidal forms, which is very characteristic and serves to outline the extent and distribution of the series.

Other rocks.—The valley of McCarthy Creek and those of the different tributaries of the Kennicott Glacier are, as has been noted, flat and

¹An expedition through the Yukon district, by C. W. Hayes: Nat. Geog. Mag., Vol. IV, 1892.

terminate abruptly northward at the foot of the great terrace or scarp which forms the edge of the main Skolai Range. This scarp and the crests above, where exposed, are seen to be made up of a series of thin bedded, slightly inclined, light-colored sedimentary rocks.

About 3 miles south of this scarp, on the top of a high peak east of McCarthy Creek, near its head, an isolated exposure of conglomerate grading upward into an impure sandstone is found unconformably overlying the shales. In this conglomerate were found several boulders of limestone which were made up almost exclusively of crinoid stems. Dr. Girty, of the United States Geological Survey, determines these as Carboniferous. Whether these boulders were originally derived from the great limestone bed overlying the greenstones, or whether they were possibly interbedded with the shales, was not very clear. It seems probable, however, that they represent a part of the great limestone formation.

Among the débris derived from the rock overlying the conglomerate were found fossils referred by Dr. Stanton to the same horizon as those found in the light-colored Cretaceous arkoses, shales, and limestones between the Lachina River and Kennicott Glacier. There can be little doubt that this conglomerate and sandstone are outliers of the sedimentary series northward in the edge of the Skolai Range and that this is the same as the series found at Kennicott Pass, which will be referred to hereafter as the Kennicott series.

At the head of McCarthy Creek the Skolai Range makes a bend to the north around the head of the Nizina, and the section as exposed on the Nizina is somewhat different from that farther west. The Kennicott series does not appear and the shales are replaced northward by a series of amygdaloidal volcanics, which are plainly younger than the Nikolai greenstone. These persist northward in the mountains on both sides of the Nizina Glacier. Toward the summit of the glacier the moraines are composed entirely of an acid volcanic, which has a groundmass inclosing phenocrysts of feldspar and hornblende. Various phases of the same rock, without other rocks, were found in the first moraines seen north of the summit at the head of the Tanana Glacier. Below the great bench in the Tanana Glacier amygdaloidal volcanics similar to those found on the southern side of the range again appear in the moraines. It is probable that many of these amygdaloidal diabbases are picked up by the ice higher up on the glacier, but do not appear until uncovered below the snow line. As no sedimentary rocks of any kind were noted in the moraines on either side of the summit, it would appear that the central mass of the Skolai Mountains is composed mainly of later volcanics. To the north of and opposite the foot of Tanana Glacier is an isolated mountain composed of vesicular basaltic lava, evidently much younger than the diabbases found along the glacier. Beyond this northward is an open



A. FOLDING AND FAULTING IN CHITSTONE LIMESTONE.

The view was taken at a point in the western wall of the Nizina Canyon, about ten miles below the foot of the Nizina Glacier.



B. AMPHITHEATER FORM OF EROSION.

This form of erosion has been ascribed to local glaciation, and this explanation is borne out by the cut, which shows a remnant of a small local glacier in the bottom of the valley. The debris rolling down the steep sides is deposited upon the wind by it carried foot-foot, where it is dumped in ridges, while the water formed by the melting of the ice percolates through the loose material without acquiring sufficient force to cut out V-shaped valleys.

valley which has already been described under the heading "Topography." The low, irregular, often flat-topped hills of this valley suggest that they are made up of basaltic lava flows similar to those of the mountain just described, at the foot of Tanana Glacier. Beyond this valley northward is the Nutzotin Range, which appears to be made up of a series of highly inclined, sedimentary rocks. Westward this valley narrows to a pass leading to the Nabesna River. On the southern side of this pass is a granitic mass similar to those described on the Kotsina and along the Chitina. To the west of this amygdaloidal volcanics are found, intimately intermingled with sedimentaries, among which are shales, slates, and limestone. A limestone bed here appears which is nearly as massive as the Nizina limestone bed on the southern side of the range. It is, however, much folded, and was seen only at a distance as a capping on a high mountain. We have here evidently a contact zone between the volcanic series southward and the Nutzotin sedimentary series northward. The general dip and strike of the Nutzotin rocks was not definitely determined, but seemed to be northward.

Northwestward, in the Nabesna Range, which forms the divide between the Nabesna and the Copper rivers, the appearance in the distance indicated flat-lying sedimentaries, very similar to those found on the southern side of the Skolai Range, called the Kennicott series. The sedimentary rocks of the Nutzotin Mountains, judging by topographic features, find their northward continuation in the Mentasta Range. The slightly inclined bedded rocks which compose the foothills northeast of Mount Sanford may readily be a continuation of the bedded rocks, supposedly sedimentary, in the Nabesna Range. On the other hand, both of these may represent bedded volcanics.

BASIC VOLCANIC ROCKS.

Two different types of basic volcanics have been described, one with the Kotsina section and the other with the Nikolai greenstones (see pp. 420 and 426). The basic volcanics of the Skolai Range, as seen in the Nizina-Tanana Glacier, are decidedly different from either of these, as is shown both in hand specimens and in thin sections. In the Nikolai greenstone amygdules are very obscure. In these younger volcanics, which may be called the Skolai volcanics, the amygdules are very fresh and conspicuous, and are filled with quartz, calcite, and epidote. In color they are usually gray to reddish brown. The massive phase is often fine-grained to aphanitic, the latter kind being in color usually almost black. In the thin section these rocks are found to be composed essentially of feldspar, pyroxene, olivine, and unindividualized base. The feldspars are often present in large phenocrysts and always in lath-shaped crystals, which frequently show a

tendency toward a parallel arrangement. The pyroxene and olivine are usually younger and fill interspaces between the feldspars. The olivine is sometimes present in large crystals and is always very much altered, usually to a reddish-brown material, which, when the crystals of olivine are large, is conspicuous in the hand specimen. Unindividualized base is always present in these rocks, and is often the most important constituent. Olivine was not found in the dense aphanitic types, and in these magnetite is usually abundant.

Numerous varieties of tuffs and volcanic breccias are common in the moraines of the Tanana Glacier. Some of these contain sufficient copper to give them a decided green tinge.

Recent highly vesicular scoriaceous lavas have been described as found in the Kotsina section (see p. 421), and rocks entirely similar to these were found in the mountain at the foot of the Tanana Glacier. The vesicles in these are empty, and the general appearance leaves little doubt that they are of decidedly later age than the Skolai amygdaloids.

ACID IGNEOUS ROCKS.

The acid rocks of the area exhibit every phase of structure from a holocrystalline granular rock to a fine-grained lava. In some cases they contain much quartz and in others none at all, but almost all contain more or less hornblende.

The coarsest-grained rock found in the area was taken from a boulder on McCarthy Creek. This was made up in large part of large phenocrysts of hornblende, with considerable biotite in large crystals, and with interspaces filled with an intergrowth of quartz and feldspar. Usually, however, the grain in the coarser phases of the more siliceous rocks is medium, and the hornblende, quartz, and feldspar mutually interlock. This is the nature of the rock found in the boss-like masses at the head of the Kotsina, eastward from the Kuskulana, and again on the pass between the Nabesna and the Tanana, and specimens of it may be found in almost every river bed in the area. At times, as on the Upper Tanana, it constitutes the greater part of the gravel on the river bottom. A frequent variation from this found in the larger dikes consists of large phenocrysts of quartz, feldspar, and hornblende bedded in a cryptocrystalline groundmass. The ultimate phase of textural variation is the rhyolitic rock found in the upper moraines of the Tanana-Nizina Glacier. This is made up of isolated small individuals of quartz and feldspar, and occasionally a little hornblende and magnetite inclosed in a felsitic groundmass, which exhibits marked flow structure. In places, and conspicuously in the great boss immediately east of the Lachina River, needle-shaped phenocrysts of hornblende are embedded in a cryptocrystalline groundmass of quartz and feldspar.

RELATIVE AGE AND PROBABLE CORRELATION.

From the foregoing it appears that in the eastern part of the area the Nizina section presents the following monoclinel series dipping northward. At the base is the Nikolai greenstone, consisting of ancient basic volcanics interfaulted with and older than the Nizina limestone. No fossils were found in the limestone, but in the overlying series Triassic fossils were collected, and in the conglomerate unconformably overlying this Triassic series boulders of a crinoidal limestone were found, which were referred to the Carboniferous by Dr. Girty, of the United States Geological Survey. These boulders were probably derived from the Chitistone limestone, or from a continuation of this in a neighboring area. It is very improbable that they were derived from any older formation. It is therefore almost certain that the Chitistone limestone is as old as Carboniferous and perhaps older. Between the Triassic shales, which have been called the McCarthy Creek shales, and the overlying or Kennicott series an unconformity was suspected. This is indicated by a conglomerate at the base of the Kennicott series and by the presence in this series of late Jurassic or early Cretaceous fossils. It is also indicated by the absence of marked folding and plication in the Kennicott series. The latter series is characterized by light-colored arkoses, shales, and impure limestone, and is typically exposed around the head of Kennicott Glacier. Northward from the section described, amygdaloidal volcanics appear, and southward from it, beyond the greenstone, is a topographic break supposed to represent a fault. Beyond this supposed fault southward the rocks are thought to be a sedimentary series with interbedded volcanics, dipping southward.

In the western part of the area, on the Kotsina River, the lowest rock observed was volcanic greenstone very similar to the Nikolai greenstone. Upon this is folded and contorted shale and slate, which is overlain by a massive bed of conglomerate, called the Kotsina conglomerate, dipping 20° to 30° southwestward and striking northwest and southeast. Beyond this conglomerate is an unstudied sedimentary series which extends to and forms the mountains that constitute the southwestern border of the main group and extend continuously eastward to the Kuskulana. At this river the sedimentary series is found to be the Kuskulana shales. The marked uniformity of topographic outline and the direction of the strike of the great underlying conglomerate on the Kotsina are thought to indicate that these youngest rocks southwest of the Kotsina conglomerate are a direct westward continuation of the Kuskulana shales. They are indicated on the map as unclassified sediments.

It has been noted that eastward from the Kuskulana a range forming the northern border of the Chitina Valley is separated from

the main mountain area northward by an open valley, along which leads the route which we followed. This range forms a direct eastward continuation of the frontal range west of the Kuskulana which was above described. And for the same reasons that the rocks above the Kotsina conglomerate are thought to be the same as the Kuskulana shales, the rocks of this eastern continuation are also thought to be the same. These reasons are, similarity in topographic forms and situation along a line thought to be the direction of the general strike of the series. However, these rocks were not examined, and in a faulted region, such as this, the impression may be erroneous. They are, therefore, indicated as unclassified sediments. It has been noted that south of the route leading eastward from the Lachina a series of sedimentary rocks appear, quite different from those to the north of this route and that, so far as examined, these consist of shales, slates, and arkoses interbedded with volcanics.

The three areas, two on opposite sides of the foot of the Kennicott Glacier and the third eastward from the Nizina River, present marked uniformity of characteristic topographical outlines. These consist of sharply serrate sawtooth crests which, as viewed from the northwest, suggest strongly bedded rocks with a southerly dip. We have then, here, seemingly, a series of sediments similar to the Kuskulana shales and also similar to the McCarthy Creek shales, but which in position do not accord with either of these. They are indicated on the map as unclassified sediments. West of the Kennicott Glacier and north of the unclassified rocks just described, the Kennicott series appears, and here seems to swing northward, across the strike of the underlying series of older rock. It appears, therefore, that while there is a general similarity between the northward-dipping Nizina section and the southward-dipping Kuskulana section, conditions which would indicate an anticlinal axis between them, the exposures between these sections are so irregular that their position can not be accounted for except by the assumption of marked faulting, possibly in two directions, and by marked local irregularity in folding. To fully elucidate this structure is beyond the possibility of reconnaissance and will require extensive detailed work over a wide area.

Northward, across the Skolai Range, the conditions seem to be less complicated, but for much of this distance the route lay along the strike of the rocks and the opportunities for observation were therefore even more limited than they were on the southern side of the area.

Table of provisional correlations.

	Spurr: Yukon district, 1896.	Brooks: White River and Tanana district, 1898.	Mendenhall: Report to the Tanana River, 1898.	Spurr: southwestern Alaska, 1898.	Eldridge: Sushitna Valley, Alaska, 1898, and Cantwell River, 1898.	Schradler: Copper River district, 1898.	Brooks: Pyramid Harbor to Fortymile River, 1899.	Rohn: Chitina River and Skolai Range, 1899.
Pleistocene	Silts and gravels.	Silts and gravels.	Sands and gravels.	Silts, sands, and gravels.	Sands, gravels, and bowlder clays.	Silts and gravels.	Silts, gravels, and volcanics.	Silts, gravels, and volcanics.
Neocene	Twelvemile beds, Porcupine beds, Nulato sandstone, Indisater conglomerate.	Tok sandstone.		Tronok beds, Hayes River beds, Nushagak beds.				
Eocene or Oligocene.	Kemai series.			Yentnu beds.	Kemai series.	Valdes series, (?) Orca series.	Tok sandstone and effusive rocks.	
Cretaceous	Mission Creek series.		Matanuska series.	Tordillo series, Holikmik series, Kolmakof series, Okline series.	Cantwell conglomerate, (?)	Valdes series, (?) Orca series.		
Jurassic				Naknek series, Skwentna series, Terra-Cotta series.				Kemite series.
Triassic								Kuskulana shales, McCarthy Creek shales.
Devonian and Carboniferous.	Tahkandit series.	Wellesley series, Nulika beds.	Sunrise series, (?)	Tachatna series.	Cantwell conglomerate, (?)	Valdes series, (?)	Nutzotin series.	Christine limestone.
Silurian	Rampart series.	Greenstone schists.	Greenstones, (?)				Greens tone schists.	Nikolai greenstone.
Pre-Silurian sediments.	Bigh Creek series, Fortymile series.	Tanana schists, Nasina series.	Tanana schists.		Sushitna schists.	Klutena series.	Kotlo series.	
Archean	Basal granite.	Gneissic series.			Basal granite and gneissic series.		Gneissic series.	

PROBABLE STRUCTURE OF THE AREA.

Dr. Hayes, who crossed the Skolai Range by way of Skolai Pass from the head of the White River and traveled down the Nizina River, says of the structure of this range:¹

The geology of the northern [the Skolai] range is simple. In the walls of Skolai Pass, by which the range is crossed, its stratigraphy and structure are magnificently displayed. The rocks are comparatively recent, for the most part Carboniferous, Triassic, and Cretaceous. A bed of limestone about 500 feet thick contains many crinoids and corals, probably of Carboniferous age. Above it are red sandstone and jasper and a great thickness of black shale.

* * * * *

Interbedded with these sedimentary rocks, and penetrating them as dikes, are fine-grained, greenish amygdaloidal lavas forming perhaps half of the whole rock mass. The structure of the range consists essentially of a broad, gentle synclinal, with a highly contorted belt on either side.

Excellent examples of typical fan structure were seen in the intensely plicated rocks which form the abrupt northern face of the range. This structure is remarkably well shown in the sides of the gorge from which Kletsan Creek issues. The 500-foot stratum of white limestone above referred to is folded in with dark greenish-black eruptive rocks, so as to form a double V; the overturned southern synclinal limbs dip southward about 30 and 45 degrees, while the normal northern limbs are nearly horizontally.

This plicated belt on the northern side of the mountains is about 6 miles wide, and south of it the synclinal in which the beds are practically horizontal (coinciding with the axis of the range) occupies a belt from 25 to 30 miles in width. On the southern side of the range there is a region of disturbed rocks similar to that on the north, but somewhat wider and less minutely plicated. The structure is well shown in the lower portion of the Nizzenah Canyon, whose walls rise from 2,000 to 3,000 feet vertically above the river.

* * * * *

Nizzenah River, for about 7 miles above its confluence with the Chittenah, flows in a narrow canyon with rocky walls from 400 to 500 feet high. For a short distance above the canyon the gravel bluffs are replaced by cliffs of calcareous black shale apparently very recent and slightly affected by the compression which has disturbed the rocks lying on the north. At the upper end of the canyon the black shale contains beds of extremely coarse conglomerate, and is succeeded by black slate and mica-schist, the latter containing many small quartz veins. An east and west line through the upper part of this canyon appears to be the approximate limit of the little altered rocks forming the northern range.

Dr. Hayes regards the Chitstone limestone as probably a continuation of the great limestone bed which he found in the vicinity of Skolai Pass and on the northern side of the range. An exposure of this forms a capping on a high, perpendicular-walled cliff which borders the valley of the Nizina on the south. This limestone is here opposite to and at almost the same elevation as the Kennicott series west of the Nizina Valley, and it appears to overlie the McCarthy Creek shales. While this appearance is probably deceptive, the occurrence of the limestone at this point shows marked and irregular displacement, and

¹ A trip through the Yukon district, by C. W. Hayes; Nat. Geog. Mag., May, 1892, Vol. IV, pp. 140-141.

shows that the section east of the Nizina Valley, described by Dr. Hayes, is somewhat different from that on the western side, herein described as the Nizina section. Dr. Hayes also describes the limestone bed as white limestone containing many crinoids and corals. This corresponds to the bowlders which were found in the conglomerate overlying the McCarthy Creek shales west of the Nizina, but the Nizina limestone, at least in the lower portion of the formation where examined, was found to be very dense and very dark in color, and in general appearance different from the bowlders in the conglomerate. It is therefore not certain that the limestone formation of which Dr. Hayes speaks is exactly the same as the Nizina limestone formation. If it is not the same formation, however, it is probably very closely related to it in point of time, and a member of the same general series of formations. There can be little doubt that the limestone which Dr. Hayes found on the northern side of the range interbedded with green amygdaloidal volcanics is the same as that which has been described by me, occurring under exactly the same conditions on the northern side of the range a little farther west, in the pass to the Nabesna River.

The synclinal structure of the Skolai Range, which Dr. Hayes mentions, was not apparent on the Tanana-Nizina section, as the bedded sedimentaries were not observed on the northern side of the range. While volcanics seem to predominate, the examination of the area was so hasty and imperfect that sediments may easily be present and have been overlooked.

The flat-lying bedded rocks of the Nabesna Range and those north of Mount Sanford more nearly resemble in appearance the bedded rocks of the Kennicott series than they do any other rocks seen throughout the entire area.

GENERAL STRUCTURE.

From the foregoing and from what has been said of the inclination of the rocks in the Valdes-Tonsina section, and of those in the section along Copper River below Taral, described by Dr. Hayes¹ and by Schrader,² it is evident that the rocks throughout the area strike in a general northwest-southeast direction. This indicates axes of major folding in this direction and makes the structure correspond with that farther northward, where in the Upper Yukon district Spurr³ shows the existence of a series of broad, gentle geanticlines and geosynclines with axes along the same general direction. A similar structure is shown by Brooks⁴ to exist in the Tanana Valley.

It appears, then, that the major folding throughout a large part of eastern Alaska is along a general northwest-southeast axis. In the

¹Op cit., p. 141.

²A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, in 1898, by F. C. Schrader: Twentieth Ann. Rept. U. S. Geol. Survey, Part VII, pp. 341-423.

³Geology of the Yukon gold district, by J. E. Spurr: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 259.

⁴Twentieth Ann. Rept. U. S. Geol. Survey, Pt. VII, p. 481.

interior this folding is gentle and open but coastward it is close and intense. The pitch of the folds and the manner in which the outcrops of formations alternately narrow and widen indicates that there is present also a series of less prominent cross folds which are obscured by the major folds.¹ In the vicinity of the Wrangell Mountains the detailed structure is further complicated by faulting in one or more directions, by local plication and local irregularity in folding, and by extensive volcanic intrusion.

Spurr, in his Yukon report,² calls attention to the fact that the general direction of mountain ranges and main drainage lines in eastern Alaska is southeast and northwest, and he shows that this is due to a series of broad, open folds along axes in this general direction; and in his reconnaissance report³ on southwestern Alaska he notes that the main mountain ranges and drainage lines of eastern Alaska are continuous westward, but that they make a right-angle turn in a zone from the head of Prince William Sound northward, and in western Alaska assume a general northeast-and-southwest direction. And he finds here a series of broad, open folds similar to those in the eastern part, but in direction at right angles to them.

Professor Van Hise⁴ has shown that major folding in one direction is almost invariably accompanied by minor or cross-folding at right angles to it, and that through shifting of the direction of maximum stress producing these folds the major folds of one area, by decreasing in intensity, become the minor folds of an adjacent area, and the minor folds of the first area, by increasing in intensity, become the major folds of the second area; but that the secondary folding is made apparent only by pitching axes of the primary folds and by dome-shaped and canoe-shaped structures. This suggests an explanation of the structure noted by Spurr and Brooks. It is probable that throughout a larger part of Alaska two series of folds are general, one series striking along southeast-northwest axes and another striking along northeast-southwest axes. Eastward and northwestward from Valdez the first series is of major importance and obscures the second, while westward and southwestward the second is of major importance and obscures the first.

MINERAL PROSPECTS.

GOLD.

Considerable work has been done on Quartz Creek, a tributary of the Tonsina, and on Ernestine and Fall creeks, tributaries of the Upper

¹ This has been also ascertained by Mr. Brooks in the Tanana region. (Ibid.)

² Op. cit., pp. 252-278.

³ A reconnaissance in southwestern Alaska, by J. E. Spurr; Twentieth Ann. Rept. U. S. Geol. Survey, Part VII, pp. 328-240.

See also Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, pp. 136, 155, 256, and map, Pl. XXXVII.

⁴ Principles of North American geology, by C. R. Van Hise; Sixteenth Ann. Rept. U. S. Geol. Survey, Pt. I, pp. 626-628.

Kanata. Enough good coarse gold has been taken out of these streams to show the presence of gold-bearing rocks in the vicinity. Working the deposits found on these streams has, however, thus far not proved economically successful on account of the great thickness of glacial drift.

A number of parties were at work during the season of 1899 on the Upper Chislechina, and one party found prospects that have led it to take in an extensive hydraulic plant, which is on the way at this time (March, 1900).

At the head of the Kotsina and in the mountains north of the Chitina Valley diabase dikes frequently carry heavy impregnations of iron pyrite and copper pyrite. A particularly large dike of this kind was noted at the head of the first tributary of the Kotsina River. Zones of similar impregnations are found in many of the larger masses of the acid rock. It is reported that assays of some of these show the presence of gold and silver, but, so far as I have been able to learn, the amounts found are too small to make the deposits of economic importance, unless cheap transportation facilities are provided.

COPPER.

Copper, both native and as a sulphide, has been found on the Kotsina, in the mountains north of the Chitina Valley, and at the headwaters of the Tanana River. The largest deposit which was seen is the so-called "Nikolai vein."¹ This has been known to the Tatal natives for a long time, and its location was disclosed by them to prospectors for a consideration of flour and provision. This was found to be a true vein deposit in a fissure due, probably, to faulting. The direction of this fissure is parallel to the strike of the rock. The main body of the ore is massive bornite, and on each side of this is a sheet of chalcopyrite. Offshoots of the main vein parallel to it are common.

This vein is found in the ancient basic volcanic greenstones, which have been called the Nikolai greenstones, and near the contact of these with the overlying Chitistone limestone.

The outcrops of this greenstone and overlying limestone, which are extensive along a persistent strike, have been already described (p. 426). Westward from the Nikolai vein in McCarthy Creek float copper was found in the river gravels below the greenstone exposure, and westward beds in the greenstones were noted in which native copper occasionally filled amygdulæ.

On the Kotsina River veins of copper ore and impregnations of native copper are reported to have been found during the latter part of the season. Specimens of the ore showed it to be the same as the bornite of the Nikolai vein.

Another vein of entirely similar ore is reported on the Sterlina, a small creek tributary to the Kuskulana from the west.

In the pass between the Tanana and the Nabesna rivers fragments of volcanic rock were found thoroughly impregnated with native copper. Time did not permit following these up to their source.

A native met on the Nabesna River indicated four different places known to him where the natives gather copper. Judging by his descriptions the easternmost of these is probably that seen by Dr. Hayes.¹ The other three are in the Upper Tanana Valley. These may all be copper placers, but even if they are they indicate the presence of copper in place in some of the rocks of the area, and their source can probably be traced out. Pebbles of diabase and volcanic tuff found in the moraine of the Tanana Glacier often showed considerable copper stain.²

It appears that the copper on both the southern and northern side of the Skolai Range is associated with basic volcanic rock. And where copper deposits were seen in place the volcanics in which they occur are associated with sedimentary rocks.

The marked similarity of the Nikolai greenstones to the Keweenaw greenstones of Lake Superior has been noted (p. 420). This similarity is apparent not only in manner of occurrence and in the appearance of the hand specimen, but also in the nature and arrangement of mineral constituents as seen under the microscope, and even in the characteristic forms of alteration. The similarity of the Nikolai greenstones to the greenstones at the head of the Kotsina and the probable equivalence of these has been noted (p. 431). The similarity of these greenstones to Spurr's Rampart series has also been noted, and in this connection it is interesting to quote a statement which he makes regarding the Rampart series. This is as follows:

The rocks of this series are characterized throughout by great basicity. The diabases contain a large proportion of idigenous sulphides and of iron and other metals as components of augite, olivine, and other bisilicates. In the tuffs, which make up a large proportion of the rocks, these materials are separated and rendered especially liable to decomposition; afterwards the rearrangement of the component elements follows naturally, and the concentration of the metals in favorable localities must be looked for. Such localities are afforded by shear zones, which may form channels for waters bearing metallic solutions derived from the decomposed diabases and tuffs, and along which these metals may be deposited under proper conditions.³

The Skolai amygdaloids, though much younger than the greenstones, are in large part very basic and contain mineral constituents very similar to those of the greenstones.

In view of the association of the copper, so far as seen, with these basic volcanic rocks and the fact that such rocks in the Lake Superior

¹ An expedition through the Yukon district, by C. W. Hayes: *Nat. Geog. Mag.*, Vol. IV, 1892, p. 144.

² On the Upper White and Tanana rivers, various copper localities are described by Mr. Brooks. See pp. 377 et seq., this report.

³ *Geology of the Yukon gold district, Alaska*, by J. E. Spurr: *Eighteenth Annual Rept. U. S. Geol. Survey*, p. 168.

region are known to be the source of the copper deposits there found, it seems reasonable to assume that these volcanics are the source of the copper in the Wrangell district—a conclusion of economic importance to the prospector, as it indicates the areas on which work should be concentrated. This is of the more importance since the volcanics have so characteristic an appearance that they can readily be recognized and traced by men who have not had the advantage of training in geology.

The fact that, so far as seen, the deposits of copper are found in the contact zones of the volcanics with the neighboring sedimentaries accords with what is known of the Lake Superior deposits and with the latest conception of ore deposits in general; and this, together with the fact that the prevailing strike of the rocks of the area is southeast and northwest, should be taken advantage of in further exploration.

In conclusion, it may be said that, while the existence of workable ore deposits has not been shown by actual exploitation, the information resulting from the year's work shows the area to be mineralized and to be favorable to mineral concentration—an area, therefore, that warrants a detailed economic survey.

APPENDIX.

The fossils collected were referred to Mr. T. W. Stanton, and his report on them is herewith appended.

The eleven small lots from as many localities seem to represent only two general horizons in the Mesozoic. The lots numbered 1, 2, 7, 8, and 13 all consist of fragments of dark, slaty rocks, with impressions of one or more species that seem to belong to *Monotis* and are referred to the Triassic. The lots numbered 3, 4, 5, and 6 all contain a small form of *Aucella*, referred to the Russian species *Aucella pallasi* Keyserling, together with fragmentary ammonites from 5 and 6. The beds from which they came are therefore provisionally referred to the Upper Jurassic, although similar forms also occur in the Lower Cretaceous. Lots numbered 9 and 12 probably came from the same horizon, but they do not contain enough fossils to make this certain. In the following list the locality designations are condensed from the original labels:

1. West side of Kuskulana River. *Monotis* sp. Triassic.
2. A short distance north of No. 1. *Monotis* sp. Triassic.
3. Boulder in creek between the Lachina and Fohlin Creek, at Camp 9. *Aucella pallasi* Keyserling. Jurassic?
4. East side of Fohlin Creek. *Aucella* sp. Weathered specimens, probably same as last. Jurassic?
5. Three miles east of Fohlin Creek, between Camps 11 and 12.
Aucella pallasi Keyserling.
Ammonites—undetermined fragments. Jurassic.

6. Canyon between Camp 13 and Kennicott Glacier.

Aucella pallasi Keyserling.

Ammonite fragments—different from those in lot 5. Jurassic?

7. West lateral moraine of Kennicott Glacier. *Monotis?* Triassic?

8. Kennicott Glacier. *Monotis*. Triassic.

9. Top of high mountain east of Camp 20, on McCarthy Creek. Obscure plant impressions pronounced unidentifiable by Professor Knowlton.

Rhynchonella? sp. Fragment. Jurassic?

Aucella sp. A single imprint.

12. Near same place as 9. *Astarte?* sp. Probably same horizon as the *Aucella*.

13. Boulder on flood plain of the Nizena River. *Monotis?* sp. Fragment. Triassic?

PRELIMINARY REPORT ON A RECONNAISSANCE
ALONG THE CHANDLAR AND KOYUKUK
RIVERS, ALASKA, IN 1899

BY

F. C. SCHRADER

CONTENTS.

	Page.
Introduction	447
Itinerary and methods of work	448
Table of distances by river	450
Routes and trails	453
Chandlar River Basin	453
Fort Yukon to Indian village in flats	453
Fort Yukon to East Fork of Chandlar River	454
Lake Creek, Grave Creek, and Middle Fork trail	454
Granite Creek and Swift River trail	454
Geroe Creek and Sheep Creek trail	454
Baby Creek and Sheep Creek trail	454
Robert Creek portage	454
Chandlar River-Dietrich River trail	454
West Fork of Chandlar to South Fork of Koyukuk	455
Chandlar River and Rampart route	455
Koyukuk River Basin	455
Koyukuk River route	455
Dall River trail	455
Rampart and Hoyn Creek trail	456
Tozi trail	456
To Fort Yukon by way of Chandlar River	456
Middle Fork route to Chandlar River	456
Allen River to Kowak River	456
Nulato trail	456
Koyukuk and Arctic coast trail	456
Population	457
Chandlar River	457
Natives	457
Whites	457
Koyukuk River	457
Natives	458
Whites	458
Climate	458
Animal life	459
Quadrupeds	459
Fish	460
Birds	460
Insects	460
Vegetation	460
Geography	462
Topography and drainage	462
Yukon Basin and Plateau	462
Chandlar River Basin	464

	Page.
Topography and drainage—Continued.	
Chandlar River Basin—Continued.	
Course of the river.....	464
Mountainous section.....	464
Yukon Plateau section.....	465
Yukon Flats section.....	465
Chandlar River.....	466
Koyukuk River Basin.....	467
Koyukuk River.....	468
Geology.....	471
Granite—probably basal.....	471
Amphibolite-schist.....	472
Rapids schist.....	473
Lake quartzite-schist.....	474
Bettles series.....	475
West Fork series.....	475
Lower Cretaceous.....	476
Upper Cretaceous.....	477
Kenai series.....	477
Nulato sandstone.....	478
Pleistocene.....	478
Till in Chandlar Valley.....	478
River gravels of Upper Koyukuk.....	478
Bench auriferous gravels of Tramway Bar.....	478
Lacustrine silts and gravels of Yukon and Koyukuk flats.....	479
Recent stream gravels.....	479
Igneous rocks other than those described.....	479
Diabase on Chandlar River.....	479
Granite on Baby Creek.....	480
Dioritic rock of Horace Mountain.....	480
Cretaceous lavas.....	481
Tertiary lavas.....	481
Basalt of Koyukuk Mountain.....	481
Basalt on Chandlar River.....	481
Mineral resources.....	482
Copper.....	482
Lead.....	482
Gold.....	482
Coal.....	485

ILLUSTRATIONS.

	Page.
PLATE LX. Map of portions of Koyukuk and Chandlar rivers.....	448
LXI. <i>A</i> , Chandlar Rapids, 128 miles above mouth of river, from west bank; <i>B</i> , View up Portage Creek, 194 miles above mouth of Chandlar River	454
LXII. <i>A</i> , Bergman and edge of plateau formed of young rock series, looking north-northwest across Koyukuk River; <i>B</i> , Peavey, looking east.....	456
LXIII. <i>A</i> , Group of Koyukuk natives at native village on left bank of Koyukuk River, 195 miles above its mouth; <i>B</i> , Mountains of limestone and mica-schist, looking up north side of Robert Creek from Horace Peak (6,000 feet), on headwaters of Koyukuk River, 652 miles above its mouth.....	458
LXIV. <i>A</i> , Mountains of limestone and mica-schist, looking down north side of Robert Creek from Horace Peak (6,000 feet), on headwaters of Koyukuk River, 652 miles above its mouth; <i>B</i> , View up Chandlar River and Valley from edge of flats, 60 miles above mouth.....	464
LXV. <i>A</i> , Mountainous topography in limestone, from Fault Mountain (5,400 feet); <i>B</i> , Mica-schist mountains, seen from Fault Mountain, west bank of Dietrich River.....	466
LXVI. <i>A</i> , View of flats on Middle Fork of Koyukuk River; <i>B</i> , Gold-bearing schist, showing cleavage and attitude of rocks in bed of Myrtle Creek	468
LXVII. <i>A</i> , Sluicing gold placers by Elsingson party, on Myrtle Creek; <i>B</i> , Young rock series of sandstone and conglomerate with some lignite.....	476
LXVIII. <i>A</i> , Silt bluffs seen from Camp 45; <i>B</i> , View up Koyukuk River, showing low, rolling plateau, bluffs, etc., 173 miles above mouth of river.....	478
FIG. 22. Profile across Koyukuk Valley above Red Mountain, showing old valley floor 750 feet above river	468
23. Faulting in sandstone below Bergman	469

PRELIMINARY REPORT ON A RECONNAISSANCE ALONG THE CHANDLAR AND KOYUKUK RIVERS, ALASKA, IN 1899.

By F. C. SCHRADER.

INTRODUCTION.

The field work on which the following report is based was done during the summer of 1899 by a party composed, besides the writer, of Messrs. T. G. Gerdine, topographer, and H. B. Baker, G. H. Hartman, T. F. Lundy, and D. C. Witherspoon. Funds for the work were allotted from the appropriation for explorations in Alaska. As much of the country to be visited north of the Arctic Circle, about the headwaters of the Chandlar and Koyukuk rivers, had never been explored, little or nothing was known about its topographic or geologic character. The purpose of the work, therefore, as set forth in the official letter of instructions, was to make a geologic and topographic reconnaissance of the Koyukuk district, embracing the upper branches of Koyukuk River and contiguous territory, to gather all possible data as to the topography, physiography, geology, and economic resources of the district traversed, and to obtain such other information concerning routes of summer and winter travel and conditions of subsistence as might be of advantage in planning future expeditions.

The time spent in actual field work was eighty days, or about two and two-thirds months, during which the work was extended by instrumental traverse from Fort Yukon, by way of the Chandlar and Koyukuk rivers, to Nulato, a distance of nearly 1,100 miles. Considerable material was collected, and many problems were disclosed which, on account of other office work, could not be worked up during the past winter (1899-1900). The following preliminary statement is therefore submitted, so as to furnish, in a general way, such information as is desired by the practical prospector and miner and other people visiting the region, the preparation of the final report being deferred for later publication.

For courtesies and material assistance in expediting the shipment of supplies and outfits over the Coast Range, the writer would acknowl-

edge his indebtedness to Supt. C. J. Hawkins, of the Skagway, White Pass and Yukon Railway, to members of the Red Line Company, and to the Canadian customs officials at Log Cabin; also to the Canadian Development Company, which, in the journey down the Yukon, extended a helping hand in the through shipment of freight.

For oral information obtained in the field thanks are due to prospectors and miners on the Chandlar and Koyukuk rivers and to Mr. Gordon C. Bettles, a well-informed pioneer in the country and keeper of the post at Bergman, on the Koyukuk. To this post a portion of the party's supplies, shipped from Seattle, was successfully and promptly delivered in good condition, via the all-water route, by the Alaska Commercial Company.

Determinations of the Paleozoic fossils referred to in this report were made by Dr. Geo. H. Girty; those of the Cretaceous, by Dr. T. W. Stanton; while such fossil plant remains as could be collected were examined by Dr. F. H. Knowlton. All of these paleontologists are connected with the United States Geological Survey. The coal analyses and mineral tests were made by the chemical laboratory of the Survey; the assays for gold and silver by E. E. Burlingame & Co., of Denver, Colo.

In conclusion, thanks are due to all the members of the party for a constantly high efficiency of service, indispensable to the success of an expedition in so remote a region, and often rendered under conditions of trial and discomfort.

ITINERARY AND METHODS OF WORK.

The Koyukuk party of 1899, composed of six men, supplies, and outfits embracing three Peterboro canoes, was landed at Skagway June 30. From here, after some delay occasioned by congestion of freight, snow-slides on the mountains, and unfavorable reports concerning the condition of lakes beyond the range, transportation was by rail to White Pass summit, thence to the foot of Summit Lake by horse sleds, thence 3 miles farther by pack animals to Camp C, and from here to Lake Bennett by wagon. After a delay of several days at Bennett on account of low water in the lake, which kept the boats aground, transportation was by steamboat down the Yukon to Fort Yukon. Owing to shallow water and the consequent grounding of the boats at Caribou Crossing and in Marsh Lake several transfers to other vessels were necessary. From the head of Miles Canyon to the foot of White Horse Rapids, a distance of about 3 miles, transportation was by horse tramway. At Dawson another change was necessary to a so-called "down-river" boat. On the upper river the boats were already overcrowded with Nome passengers, but below Dawson the press became very much worse, so that a short night's lodging in

MAP
OF
PORTIONS OF
KOYUKUK AND CHANDLAR RIVERS

WITH GEOLOGIC NOTES

F. C. SCHRADER GEOLOGIST
TOPOGRAPHY BY T. G. Gerdine
1899

Scale 1:625,000

Contour interval approximately 500 feet

Intermed. intervals of 100 feet are shown by dotted contours

Dates mean sea level Dates refer to camps

Streams which have been traversed
not been traversed



one's own blanket on the hurricane deck, on the floor of the cabin, or in the wood pile of the engine room was considered a luxury.

As the astronomic position of Fort Yukon was known, having been determined by Captain Raymond,¹ after verification of the observations by Mr. Gerdine, field work was begun at this point by canoe June 22. From here it was carried $26\frac{1}{2}$ miles down the Yukon to the mouth of Chandlar River; thence 200 miles up the Chandlar to its headwaters, and by portage across the mountains to the headwaters of the Koyukuk, and 700 miles down this river to Nulato, also a point of known astronomic position.²

The ascent of Chandlar River was made by towing or "tracking" the canoes up by line, and the use of oars, poles, paddles, or wading, as the varying conditions required. During most of this section of the trip it required hard work to make 4 or 5 miles a day, on account of the swiftness of the current and the frequently impassable condition of the banks for tracking. At Chandlar Rapids (Pl. LXI. A) it was found necessary to portage canoes and cargo for about one-eighth of a mile. Between the headwaters of the Chandlar and those of the Koyukuk, a portage (see Pl. LXI. B) of 15 miles, a few days' aid was received from a white prospector and a few Chandlar River natives.

From the mouth of Bettles River, on the Koyukuk, the party ascended Dietrich River for a distance of 20 miles. From the mouth of Slate Creek a detachment of the party in charge of Mr. D. C. Wither- spoon portaged across to the South Fork of the Koyukuk and carried a compass traverse down that stream to its confluence with Middle Fork, a distance of approximately 140 miles. Later the progress of the party was somewhat expedited by the employment of two prospectors to help carry on the work in descending the Koyukuk below Bergman. The work was finally completed at Nulato September 14, whence the party returned home by way of St. Michael and Unalaska, after visiting the newly discovered Nome gold region on the way.

In the absence of monuments or sight points for triangulation through the Yukon Flats and along the Chandlar and the lowlands of the Koyukuk, the instrumental measurement was carried on by stadia. Through the less flat and the mountainous country it was by triangulation. A stop was made every three or four days to ascend mountains and occupy prominent stations for this work. The journey to these points, sometimes 5 or 6 miles from the river, also afforded opportunity, though rather limited, for topographic and geologic observations and for photography. The astronomic and other principal observations were made by transit, and the topography was done principally by means of the plane table and telescope alidade.

¹ The position of this place is latitude $66^{\circ} 33' 47''$, longitude $145^{\circ} 17' 47''$. Report of a reconnaissance of the Yukon River, Alaska Territory, 1869, by Capt. Charles W. Raymond: Ex. Doc. No. 12, Senate, Forty-second Congress, first session.

² Loc. cit.

TABLES OF DISTANCES BY RIVER.

Distances by river along the Chandlar from mouth of river on the Yukon to summit of Chandlar River—Robert Creek—Koyukuk portage.

[Surveyed by T. G. Gerdine in 1899 by triangulation and stadia.]

Locality.	Distance from mouth of Chandlar River on the Yukon.	Distance from summit of portage.
	Miles.	Miles.
Mouth of Chandlar River	0	197
Native houses, or Fish Camp	7.44	189.66
Camp 11, at edge of flats and mountains	60.04	137.96
Mouth of East Fork of Chandlar River	65.54	131.46
Mouth of Middle Fork	96.74	100.26
West Fork or portage to South Fork of Koyukuk ..	114.54	82.46
Chandlar River rapids	121.89	75.11
Mouth of Chandlar Lake	129.89	67.11
Camp 23, at head of Chandlar Lake	136.39	60.61
Baby Creek	138.89	58.11
Portage to Middle Fork of Chandlar River	158.49	38.51
Camp 28, at mouth of Portage Creek	193	4
Summit of Robert Creek—Koyukuk portage	197	0

NOTE.—From Camp 28, at mouth of Portage Creek, to forks above it, is 7 miles, or 204 miles from mouth of river.

Distances by river along the Koyukuk from summit of Chandlar River—Robert Creek—Koyukuk portage (latitude $67^{\circ} 50'$, longitude 149°) to the mouth of Koyukuk River on the Yukon.

[Surveyed by T. G. Gerdine by triangulation and stadia in 1899.]

Locality.	Distance from summit of Chandlar River—Robert Creek—Koyukuk portage to mouth of Koyukuk on Yukon.	Distance from mouth of Koyukuk on River—Robert Creek—Koyukuk portage.
	Miles.	Miles.
Summit of Chandlar River—Robert Creek—Koyukuk portage	0	663.87
Sheep Creek	10.50	653.37
Camp 30 and Horace Peak	12	651.87
Head of Robert Creek Canyon	16.50	647.37
Mouth of Phæbe Creek and head of Bettles River	19.75	644.12
Foot of canyon	27	636.87

Distances by river along the Koyukuk from summit of Chandlar River-Robert Creek-Koyukuk portage (latitude $67^{\circ} 50'$, longitude 149°) to the mouth of Koyukuk River on the Yukon—Continued.

Locality.	Distance from summit of Chandlar River- Robert Creek- Koyukuk portage to mouth of Koyukuk on Yukon.	Distance from mouth of Koyukuk on Yukon to summit of Chandlar River-Robert Creek-Koyukuk portage.
	<i>Miles.</i>	<i>Miles.</i>
Mary Creek.....	28.50	635.30
Limestone Creek.....	30	633.87
Lower Canyon on Bettles River.....	37.50	626.37
Confluence of Bettles and Dietrich rivers, forming Middle Fork of Koyukuk River..	41	622.87
One and One-half Mile Canyon.....	51	612.87
Nelson Creek.....	59	604.77
Wiseman Creek.....	64.10	599.77
Marion Creek.....	73	590.87
Camp 37, at mouth of Slate Creek.....	77.25	586.62
Porcupine Creek.....	80.25	583.62
Camp 38, at mouth of Rose Creek.....	83.85	580.02
Twelvemile Creek.....	85.85	578.02
Tramway Bar, at head of canyon.....	94.25	569.62
Pasco Creek.....	96.25	567.62
South Creek.....	104.25	559.62
North Fork of Koyukuk.....	114.06	549.81
Harriet Creek.....	117.36	546.51
Creek from south.....	125.86	538.01
Hokotena River.....	126.21	537.66
Colored Creek.....	133.31	530.56
Totsenbetna River.....	141.13	522.74
Fickett River.....	154.09	509.78
Twomile Bluff, on left and right.....	158.48	505.39
Peavey.....	172.27	491.60
South Fork of Koyukuk.....	176.27	487.60
Sozhekla River.....	187.29	476.58
Head of islands.....	199.56	464.31
Allen River.....	213.46	450.41
Arctic Circle.....	219.79	444.08
Bergman <i>a</i>	223.29	440.58
Arctic City.....	227.32	436.55
Oldman Creek.....	227.44	436.43
Red Mountain.....	259.82	404.05
Cretaceous fauna in limestone.....	288.07	375.80

a The Arctic Circle is 11 miles north of Bergman in direct line.

452 RECONNAISSANCE ON CHANDLAR AND KOYUKUK RIVERS.

Distances by river along the Koyukuk from summit of Chandlar River—Robert Creek—Koyukuk portage (latitude 67° 50', longitude 149°) to the mouth of Koyukuk River on the Yukon—Continued.

Locality.	Distance from summit of Chandlar River— Robert Creek— Koyukuk portage to mouth of Koyukuk on Yukon.	Distance from summit of Koyukuk on Yukon to summit of Chandlar River—Robert Creek—Koyukuk portage.
	<i>Miles.</i>	<i>Miles.</i>
Head of islands, Waite Island	294.44	369.43
Camp 50, Alashuk River	297.07	366.80
Cretaceous fauna in limestone	305.07	358.80
Cretaceous fauna, bluff on right bank	312.00	351.87
Creek from southeast	325.97	337.90
Batza River	341.76	322.11
Hogatza River	369.14	294.73
Point Winthrop, south rapids, head of island	386.24	277.63
Dakli River	419.67	244.20
End of Cut-off and Treats islands	440.47	223.40
Huslia River	462.22	201.65
Native village on left	469.08	194.79
Stream from west; bluffs begin on right	484.66	179.21
Dulbi River	507.99	155.88
Dagitli River and native village	529.95	133.92
Kateel (?) River	587.49	76.38
Bitzla River	604.27	59.60
Gisasa River	611.03	52.84
Mouth of Koyukuk River on Yukon	663.87	0

Distances along Dietrich River from its mouth and from mouth of Koyukuk.

Locality.	Distance from confluence of Die- trich and Bet- tles rivers, form- ing south Fork of Koyukuk, up Dietrich River to David Creek.	Distance by river from mouth of Koyukuk River on Yukon to points on Die- trich River above confluence of Dietrich and Bet- tles rivers, form- ing south Fork of Koyukuk.
	<i>Miles.</i>	<i>Miles.</i>
Confluence of Dietrich and Bettles rivers, forming South Fork of Koyukuk	0	622.87
Gibson Creek	17	639.87
Fault Mountain	20	642.87
David Creek	23.50	646.37

* Bitzatoilocta on Lieutenant Allen's map (1885).

NOTE.—From mouth of Koyukuk River on Yukon down the Yukon to Koyukuk Station is 5.45 miles, and from mouth of Koyukuk to Nukato is 22.20 miles.

Approximate distances by river along South Fork of Koyukuk.

Locality.	Distance from confluence of Middle and South forks of Koyukuk.	Distance from mouth of Koyu- kuk, on Yukon.
	<i>Miles.</i>	<i>Miles.</i>
Confluence of South and Middle forks of Koyukuk.....	0	487.60
Union City	1	488.60
Fish Creek	31	518.60
Seaforth.....	45	532.60
Soo City.....	50	537.60
Jintown and Jim Creek	65	552.60
Cripple Creek.....	94	581.60
Mosquito Fork.....	107	594.60
Hungarian Creek	115	602.60
Summit of portage between South Fork of Koyukuk and West Fork of Chandlar....	145	632.60

*Approximate distances from mouth of Slate Creek on Middle Fork of Koyukuk to mouth of
Hungarian Creek on South Fork of Koyukuk.*

Locality.	Mouth of Slate Creek.	Mouth of Hungarian Creek.
	<i>Miles.</i>	<i>Miles.</i>
Mouth of Slate Creek on Middle Fork of Koyukuk..	0	20
Mouth of Myrtle Creek (up Slate Creek).....	8	12
Summit of portage between Slate Creek and Hun- garian Creek.....	13	7
Mouth of Hungarian Cr. on South Fork of Koyukuk.	20	0

ROUTES AND TRAILS.

The Chandlar and Koyukuk River regions form no exception to the rule of Alaskan travel. The almost invariable means is by boat or canoe along the waterways in summer, and overland by trail with the use of dog sleds in winter. The term "trail," as used in Alaska, refers more particularly to the passable condition of the country than to any foot-beaten path or well-worn line of travel. This is especially true of the Chandlar and Koyukuk regions.

CHANDLAR RIVER BASIN.

Fort Yukon to Indian village in flats.—A native trail is known to lead from Fish Camp, on the Yukon, to the Indian village in the flats on the Chandlar River, about 8 miles above its mouth. This same

point is reached by overland trail in winter from Fort Yukon across the Porcupine River.

Fort Yukon to East Fork of Chandlar River.—From Fish Camp, above mentioned, the route continues up the Chandlar River to near the edge of the flats, thence more directly northwestward through the low mountains to East Fork village, a distance of about 80 miles from Fort Yukon. In winter the East Fork natives, it is reported, sometimes travel eastward to the Porcupine and then descend that river to Fort Yukon.

Lake Creek, Grave Creek, and Middle Fork trail.—This is a short route of about 20 miles between the main Chandlar River above the lake and the headwaters of Middle Fork, by way of Lake Creek and Grave Creek. So far as known, it is used only by the natives in their hunting and fishing trips.

Granite Creek and Swift River trail.—On the Chandlar River below West Fork the country is reported to be easily passable up Granite Creek and by way of a low portage down "Swift River," and possibly the lower part of the Dall to the Yukon near Fort Hamlin. The Chandlar River natives are reported to use this route occasionally in going to Fort Hamlin for trading purposes.

Goose Creek and Sheep Creek trail.—This merely denotes that the country is passable with light pack over the mountainous divide between the heads of these two creeks, the latter of which drains westward, finally reaching the Koyukuk. The rise seems to be considerable. The distance is about 15 miles.

Baby Creek and Sheep Creek trail.—This leads from the region about the head of Chandlar Lake by way of Baby Creek to the head of Sheep Creek, above mentioned. The divide, however, seems to be high and rugged. The route is probably but little used, even by the natives, and then only in their hunting trips. The length of the trail, from the mouth of Baby Creek to the mouth of Sheep Creek, is about 20 miles.

Robert Creek portage.—This is the route used by the party during the past summer (1899) in portaging from practically the head of navigation on the Chandlar River to that of Robert Creek, on the Koyukuk River, a distance of 15 to 20 miles. Considering the ruggedness of the surrounding country, the portage is good. On the Chandlar River side it follows along the slope of a prominent sway in the divide, shown in Pl. LXI, B. At the bottom of the sway a steep-walled canyon has been intrenched to a depth of 100 feet or more. The summit of the portage has an elevation of about 3,000 feet, the rise being about 1,000 feet above the Chandlar River.

Chandlar River-Dietrich River trail.—It is also possible that by ascending Chandlar River above the sixty-eighth parallel to very near its headwaters, and going light, a portage could be made across to the



A. CHANDLAR RAPIDS, 128 MILES ABOVE MOUTH OF RIVER, FROM WEST BANK, LOOKING N. 45° E.



B. VIEW UP PORTAGE CREEK, 194 MILES ABOVE MOUTH OF CHANDLAR RIVER, LOOKING S. 13° W.

Dietrich River. The natives, however, denounce this region as very rough.

West Fork of Chandler to South Fork of Koyukuk.—From reports of a few prospectors who have crossed this portage it is known to be easy and the divide low (see map, Pl. LX), so that during the wet season or at high water the distance of actual portage between points of canoe navigation is reduced to 10 miles or less. The creek through which the western side drains into the South Fork of the Koyukuk is said to be called Eldorado. During the past season (1899) many of the miners on the Upper Koyukuk were contemplating sledding their supplies from Fort Yukon up the Chandler River and into the Koyukuk by this route. It traverses little if any rough country, but the distance is about 150 miles from Fort Yukon.

Chandler River and Rampart route.—This name is here given to the route followed southward by some of the Chandler natives, along the divide between the Koyukuk and the Yukon to Fort Hamlin, at the head of the Lower Ramparts, for trading purposes.

KOYUKUK RIVER BASIN.

Koyukuk River route.—The easiest and most practicable way of entering the Koyukuk region in summer, especially with freight, is to ascend the Koyukuk by flat-bottomed steamboat. About 1,500 people entered the country in this way during the season of 1898. Bergman (see Pl. LXII, 11), 440 miles above the mouth of the river, is reached by steamboat throughout the open season. This may, in a general way, be considered the head of steamboat navigation on the Koyukuk. Above Bergman certain sections of the river contain bars and shallows which render navigation more or less difficult except at high water. During high water, however, steamboats ascended to above Tramway Bar, 100 miles or more above Bergman, and also for considerable distances up the Allen and other large northwest tributaries during the summers of 1898 and 1899.

Dall River trail.—This route leaves the Yukon River at the head of the Lower Ramparts, near Fort Hamlin, leads northward up the Dall River, then northwestward over the divide, and descends Fish Creek to the South Fork of the Koyukuk near the Arctic Circle, a distance by trail of about 100 miles from the Yukon. Up to the present time this has apparently been the principal overland route used by prospectors in entering the Koyukuk. By continuing farther up the Dall some have descended Jim Creek, thus reaching the South Fork of the Koyukuk at Jintown. It is reported to be also feasible to cross from the Dall to Oldman Creek and down this stream to the Koyukuk below Bergman. This latter, however, seems questionable, as the portage must be very long.

Rampart and Hoyn Creek trail.—This route is known by report only, but it is said to be easier and shorter than the Dall River trail. It is reported to ascend Hoyn Creek, a tributary of the Yukon, near Rampart, cross a low pass in the mountains, and thence a wide, level stretch of country, a total distance of about 90 miles, and to come out on the Koyukuk about 80 miles above Bergman, probably at Fish Creek, the same as the Dall River trail.

Tozi¹ trail.—This route leaves the Yukon about 6 miles below the mouth of the Tozi River and leads nearly northward, mostly along the low divide between the Tozi and Melozi rivers, to near the head of Oldman Creek, which it descends to the Koyukuk, near Bergman. This is the route followed by Lieutenant Allen in 1885. Its length from the Yukon to the Koyukuk is about 90 miles. The Tozi may also be ascended by canoe nearly to its headwaters, and the route continued thence by portage to Oldman Creek, as above.

To Fort Yukon by way of Chandlar River.—This route has already been noted under the Chandlar River region trails. Leaving the South Fork of the Koyukuk by way of Eldorado Creek and crossing the low divide, it descends the West Fork of Chandlar River, thence down the river as directly as practicable and across the Yukon Flats to Fort Yukon, about 100 miles distant from the Koyukuk.

Middle Fork route to Chandlar River.—This route, as explained on page 454, is up Bettles River and Robert Creek, and thence by a 15-mile portage to the headwaters of the Chandlar, about 50 miles by river above Chandlar Lake. The portage is fair, but the current in Bettles River and Robert Creek is too swift and the bed too bowl-dery to permit a safe or easy ascent with a loaded canoe or boat.

Allen¹ River to Kowak River.—A route is known to exist by way of Allen to the headwaters of the Kowak, but as it seems to be used only in winter, the length of the portage is not known. Some Kowak River prospectors sledged across it to the Koyukuk in March, 1899. The Allen is a large stream and can be ascended nearly 40 miles by a light-draft, flat-bottomed steamboat.

The country is also said to be portageable between the headwaters of the Alashuk and the Kowak rivers, and also between the Dagitli and the Kowak. This latter portage was made by Captain Stone in 1885.

Nulato trail.—This is a "cut-off" or short overland trail of about 25 miles from the west bend of the Koyukuk about 7 miles above the mouth of the river to Nulato. In winter a sledge trail leading directly north from Nulato up the Koyukuk is sometimes used.

Koyukuk and Arctic coast trail.—According to reports which seem to be authentic, the Malamut natives of the Arctic coast have been known to visit the head of the Koyukuk Basin. They are supposed

¹ Formerly "Tozikakat," "Allenakat," etc. For Alaskan names see pp. 487-509 of this report.



.1 BERGMAN AND EDGE OF PLATEAU FORMED OF YOUNG ROCK SERIES LOOKING NORTH-NORTHWEST ACROSS KOYUKUK RIVER



.2 PEAVEY, LOOKING EAST.

to have found passage through the mountains at the head of Dietrich River and to have descended this stream, but of this there is no certainty. The country in this region, however, is too rugged to be of promise for a practicable route of any sort, as shown in Pl. LXV, A, and on the map (Pl. LX).

POPULATION.

CHANDLAR RIVER.

Natives.—By estimate the Chandlar River natives number about 50 in all. A small settlement, of which the nucleus is a couple of cabins, is found in the flats about 7 miles above the mouth of the river. Most of the natives, however, live beyond the flats, in the mountainous part of the country. Their principal village is on East Fork, remote from the influence of the Yukon travel and traffic. For subsistence they depend principally upon game and fish. A few months during the coldest part of the winter are spent in log cabins or winter tents, and the remainder of the year in roaming about, wherever game or fish may furnish food. In winter the skins collected during the year are exchanged for tea, tobacco, clothing, and other necessities, at Fort Yukon and Fort Hamlin. Though the natives subsist almost exclusively upon game and fish, with some berries during summer, they have a keen relish for white man's food. They are shiftless and improvident, and their destitution and suffering are occasionally great. They are, however, comparatively intelligent. Some who have attended mission schools at Fort Hamlin have learned to read and write.

Whites.—Four white men, all prospectors, were the only whites in the region in 1899. Two of these were connected with the natives by marriage.

KOYUKUK RIVER.

Natives.—The Koyukuk natives, also known as Koyukons, number fewer than 200, so far as can be judged. The Eleventh Census places the number at 174. Their habits of life are much the same as those of the Chandlar natives. They have no cabins on the extreme upper waters much above the sixty-seventh parallel. At present the population, so far as observed, is scattered along the river in small villages containing but a few families and cabins, generally near the mouth of some tributary. There are also some on the Allen and other tributaries. So far as learned, there are no missions nearer than Nulato and Fort Hamlin.

Nulato seems to have been their chief trading post before the location of the post on the upper river. At these upper posts the natives are frequently employed by the whites, and some are also employed

by the river steamboats. They are generally peaceful. Types of the Koyukuk natives are shown in Pl. LXIII. *A*.

Whites.—Until two years ago the white population of the Koyukuk was small, though there had been a post on the site of Arctic City for some time, and the country was visited by a few prospectors early in the nineties or before. During the Klondike rush of 1898 there was an influx of nearly 1,500 people, mainly would-be prospectors or gold seekers, embracing men of nearly every profession and calling, organized in parties of from 20 to 80. They ascended the river in flat-bottomed steamboats to various points, where they spent the winter. One of the largest white settlements during 1898-99 was at the present site of Arctic City, almost on the Arctic Circle, where a town of 500 or 600 people was formed, which was lighted by electricity throughout the long, dark winter. Many also wintered at Bergman, Union City, Peavey, and other points. On the opening of navigation the following spring (1899) most of this population, having gained some experience and seeing little gold in sight, descended the river by boat and left the country, some going to Cape Nome and many returning to the States. In August, 1899, there were estimated to be about 100 white men in the country, mainly miners and prospectors, about the new discoveries on Slate Creek and neighboring streams. There were also some on the South Fork and others at Bergman, Arctic City, and Peavey (see LXII. *B*). They were prepared to remain in the country during the winter of 1899.

The principal supply post is at Bergman (Pl. LXII. *A*), near the Arctic Circle, at the head of steamboat navigation on the Koyukuk. The post is kept by Pickarts, Bettles & Pickarts, to whom supplies are delivered each season by the Alaska Commercial Company. During the past season there was also a liberal supply of canned goods stored at Peavey, and preparations were being made by Pickarts, Bettles & Pickarts to open a new post on Slate Creek, in the newly discovered diggings. Much freight was en route for this purpose. According to reports, many people went into the region from the various camps along the Yukon during the months of February and March, 1900.

CLIMATE.

The climate on the Chandlar River is similar to that on the Upper Yukon, but is not so bright nor usually so warm in summer. The amount of precipitation is small. During the summer there is considerable cloudiness, with some foggy, showery, stormy, or windy days, but no great amount of rainfall. The average temperature, as taken on the trip, during the month of July, 1899, was approximately 55° F., with a maximum of 73°; for the month of August the



A. GROUP OF KOYUKUK NATIVES AT NATIVE VILLAGE ON LEFT BANK OF KOYUKUK RIVER,
195 MILES ABOVE ITS MOUTH.



B. MOUNTAINS OF LIMESTONE AND MICA-SCHIST, NORTH SIDE OF ROBERT CREEK, FROM HORACE
PEAK 16,000 FEET; ON HEADWATERS OF KOYUKUK RIVER, 675 MILES ABOVE ITS MOUTH,
LOOKING N 15° E

average was about 58° , with a maximum of 74° . The winter season is also much the same as at Fort Yukon, but it is possibly somewhat colder, as it is farther north. Prospectors report a temperature of from 60° to 70° below zero in the month of February. On cutting holes through the ice in Chandlar Lake, in March, to procure water and fish, the ice was found to be $6\frac{1}{2}$ feet thick.

In the upper part of the Koyukuk Basin the climate seems to be about the same as on the Chandlar River, but farther down it is moister, partaking more of the nature of the climate about Nulato and the Lower Yukon, with an increased amount of precipitation. According to the records of Mr. W. H. Windrick, keeper of the post at Peavey, ice was running on the river at Peavey as early as September 20, 1898, and about a month later the river was frozen over and remained so until spring. February is reported to be the coldest month, during which the average temperature was 55° below zero, and the minimum 72° below. At Jintown, 30 miles north of Peavey, on the South Fork, a minimum of 80° below zero is reported to have been recorded by spirit thermometer. At Peavey the ice on the river broke on the 19th of May, 1899, and the water reached its highest mark for that season, about 6 feet above normal, early in July.

ANIMAL LIFE.

The following list of animals, based entirely on observations of the party and on authentic reports of prospectors, though reliable as far as it goes, is probably incomplete.

Quadrupeds.—Moose, caribou, mountain sheep, bear, wolf, mink, squirrel, and porcupine are found on the Chandlar River. They are nearly all confined to the mountainous part of the region. To the natives moose, caribou, mountain sheep, and bear are the principal large game. All are very important for food and clothing. Moose are not plentiful, but some are taken each year by the natives. Caribou are seen in the region only occasionally during the migrating season, usually in herds, but are not known to remain long.

During the grazing season the sheep range in the mountains along the upper waters of both the Chandlar and Koyukuk rivers, but in winter they find refuge in the more sheltered lowlands of the Koyukuk.

The only species of bear learned of is the black bear, an animal of medium size. The large brown bear may, however, be present.

The wolves seen by the party were large-sized gray wolves, one of which was killed. These animals may be seen both in the flats and in the mountains.

The principal squirrel is a large brown-striped ground squirrel. This small animal is very abundant. Its home is in the lower reaches of the valleys, where it burrows extensively. It is usually caught in steel traps, like a rat. Its flesh is much used by the natives for food and its pelts are made into clothing.

Fish.—The principal fish is salmon. Both king salmon and dog salmon are reported to ascend the East Fork of the Chandlar, where they are caught and dried in a small way by the natives for food. They do not, however, reach the lake or the main river, probably owing to the swift rapids, which they apparently can not ascend. A rather large-sized fish known as white-fish is also much used. Pike, pickerel, and two other species of fish are reported to occur in the lake. In the small lakes away from the river fine speckled trout and several other kinds of fish are said to be found.

Birds.—The principal indigenous birds are the grouse and ptarmigan. In summer geese and ducks are found along the streams and lakes. The gull is common, and hawks, buzzards, and a crow or black raven were also noted. The region is also visited by many species of the smaller migratory birds of the temperate climate during the summer months.

Insects.—The principal and most annoying insects noted were the mosquito, throughout the region, and *Pediculus vestiment*, on the natives. The mosquitoes, however, were not so numerous as in most other years. A few bees and some medium-sized butterflies were noted about the wild flowers in the valleys, and a few species of beetles are common.

VEGETATION.

A hasty collection of the flora of the region was made by the writer along the route, of which a list and fuller description will be published later.

The principal timber on both the Koyukuk and Chandlar rivers is spruce. Different species of poplar, with birch, alder, and willow, are also present. In the flats along the Chandlar River the stand of spruce is much the same as elsewhere in the Yukon Flats. It varies from dense to thin, with occasionally more or less barren areas. The trees, which seem in general to be young, probably average less than a foot in diameter at the base. In certain localities, however, some exceed 2 feet and attain a height of nearly 100 feet. In the mountainous part of the valley, below West Fork, the timber line rises to an elevation of about 2,600 feet. One of the best timber areas, covering probably one hundred or more square miles, occurs in the lowland southwest of the Big Bend below West Fork. Here the timber is nearly all spruce.

On the granitic belt of rocks along the south side of the valley, from a point opposite East Fork nearly to Granite Creek, the timber is represented principally by a fair stand of young birch. Above Chandlar Lake the timber line usually rises but a few hundred feet above the edge of the valley flat, where the timber already becomes quite dwarfed. In the more open tributary gulches, however, the timber may ascend considerably higher, but usually ceases at a height of 600 or 700 feet above Chandlar River Valley, nor does any occur much above the head forks, at about 7 or 8 miles above Robert Creek portage. On the Koyukuk side of the portage the timber line is again found at about the same elevation. Timber is first seen on Robert Creek, about 8 miles from the summit of the portage, or about 11 miles from timber line on the Chandlar River side. Toward the head of Dietrich River, on the Koyukuk, the timber seems to vanish much the same as on the Chandlar River.

From the confluence of the Dietrich and Bettles rivers the timber, which occurs more or less all the way down the Koyukuk, is principally spruce and cottonwood. On the lower 5 or 6 miles of Slate Creek many of the trees approach 2 feet in diameter and are 80 or 100 feet in height, while some may exceed this.

Heavy timber is also reported to occur on the Allen and other large northwest tributaries. A sawmill is operated at Bergman and one at Union City.

Considerable birch also occurs on the Koyukuk. Of that observed none was larger than 5 or 6 inches in diameter. The alder and willow, both on the Koyukuk and Chandlar rivers, though often of dense and rank growth, do not attain to real tree or timber size.

Roses and other wild flowers grow in some localities in more or less profusion. Grass, usually in limited amount, occurs in small patches along the margins of the streams and elsewhere in the valley flats. Some also grows on the mountains up to a height of 4,000 or more feet, where it forms the grazing ranges of the mountain sheep.

The most universal type of vegetation throughout both regions is the moss. Here, as elsewhere in Alaska, the surface is nearly everywhere clothed with it. It extends from the flats into the mountains to an elevation of nearly 5,000 feet.

Of the edible vegetable products growing wild the principal are the blueberry, red currant, and salmon berry. The blueberry is nearly everywhere abundant, and is extensively used. The currant is not so common, though in some localities it is quite abundant. Cranberries and moss berries also abound.

At Bergman ordinary garden vegetables were grown by Mr. Bettles with fair success, while in the mission gardens at Nulato, conducted in cooperation with the natives, the more hardy vegetables are grown on a somewhat large scale.

GEOGRAPHY.

The country under consideration lies in the north-central part of Alaska, between the Yukon River on the south and the Arctic Ocean on the north, and our line of reconnaissance extended for a distance of more than 1,000 miles. It can not, therefore, be considered as a compact area, but may be best described in two parts. The first part extends from Fort Yukon, at the great bend or elbow of the Yukon River and on the Arctic Circle, in approximately $66\frac{1}{2}^{\circ}$ north latitude and 145° west longitude, for about 170 miles in a straight line, or more than 200 miles by river, northwest into the highland or mountainous country, in approximately 68° north latitude and 150° west longitude. The southeastern 70 or more miles of the belt lies in the well-known Yukon Flats, while the remaining northwestern portion lies in the highland belt and rugged mountains, where much of the country had never before been explored.

The second part of the route, which forms practically a right angle with the first, traverses a considerable belt of country, extending from the mountains in the region of the sixty-eighth parallel about 330 miles in a straight line, or nearly 700 miles by river, southwestward to Nulato, below the mouth of the Koyukuk River, on the Yukon, in approximately $64\frac{2}{3}^{\circ}$ north latitude and 158° west longitude. It is about 170 miles in a straight line from St. Michael. The northeastern 80 miles lies in the rugged region on the south slope of the Rocky Mountains, while the remaining 250 miles are in the low, rolling, and somewhat flat country of the Koyukuk Valley.

At the most northern point attained the two parts of the route form, as stated, a right angle and the two sides of a right-angled triangle. Of this the eastern, or Chandlar, part of the route from Fort Yukon to the sixty-eighth parallel forms the shorter leg, and the western, or Koyukuk, the longer leg, while the Yukon River from Fort Yukon to Nulato, a distance of about 400 miles, forms the hypotenuse. Portions of the country lying within this large triangle between the Yukon and the Koyukuk have been visited by prospectors and explorers, but much yet remains to be explored, especially from a geologic and topographic point of view. The same is more forcibly true of the rugged region north of the route traversed, between the sixty-eighth parallel and the Arctic Ocean, and especially of the large area of northwestern Alaska between the Koyukuk and the Arctic coast on the northwest.

TOPOGRAPHY AND DRAINAGE.

YUKON BASIN AND PLATEAU.

Since the area considered lies within the drainage basin of the Yukon, it will be well to note, though very briefly, the aspect of this great natural feature of the earth's surface in Alaska.

The Yukon River heads in British Columbia and the Northwest Territory. Omitting its great northward bend or elbow at Fort Yukon, its trend is, roughly considered, nearly westward through Alaska to Bering Sea, approximately along the sixty-third parallel. In area this drainage basin ranks among the largest river systems of the world, covering some 440,000 square miles. It consists, for the most part, of an elevated and more or less deeply dissected highland, to which has been applied the name Yukon Plateau. It is virtually an extensive north-westward expansion of the British Columbia Plateau, which gradually widens as the mountains diverge northward and finally embrace the Yukon Plateau. The general elevation of this plateau is about 5,000 feet, but it descends toward the northwest and inward toward the axis of the basin.

The mountains which skirt the plateau on the south and rise high above it are the St. Elias and other coast ranges, and farther north the Alaskan Mountains, while those which form its boundary line on the east and northeast are the Rocky Mountains, these being the northward continuation of the Rocky Mountains of the United States. In their extension northward through the Northwest Territory near to the Arctic coast they continue to form the Continental Divide, and they here form the watershed which separates the drainage flowing eastward into the Mackenzie from that flowing westward into the Yukon Basin. Near the Arctic Ocean the Rocky Mountains spread westward, embracing the Davidson Range and forming the divide between the Arctic Ocean on the north and the Yukon Basin on the south. They are reported to soon diminish in height and to die out at about the one hundred and forty-first meridian. Here, however, the elevation is still from 5,000 to 7,000 feet, and, judging from observations during the past season, the mountains may be continued westward at about this elevation in a rugged highland belt, some 50 or more miles in width, to the one hundred and fifty-first meridian, beyond which they probably diminish more or less rapidly in elevation.

In looking northward from the top of the mountains at Chandlar Lake, the more distant and highest of these mountains seen between the one hundred and fifty-first and one hundred and forty-ninth meridians have the appearance of being fronted by several successively lower subranges or narrow belts of dissected country; but in general a distant view from the top of the mountains across a wide stretch of country gives the aspect of a deeply dissected former plateau, the peaks and dominant crests having a general level (see Pl. LXIV, A). To a part of these mountains, between the one hundred and forty-first and one hundred and forty-fourth parallels, apparently overlooking the tundra belt which skirts the Arctic Ocean, the names Franklin and Romanoff mountains have been given.

On the south, in the region visited, these mountains descend somewhat rapidly from 5,000 feet to the edge of the Yukon Plateau, about

3,000 feet in elevation, crossing the Chandlar and the Koyukuk rivers a little north of the sixty-seventh parallel, the former above West Fork and the latter in the region of Slate Creek. From Slate Creek the edge seems to continue, with some decrease in height, northwestward across the upper waters of the several large tributaries of the Koyukuk, all of which seem to head in the mountains beyond the edge of the plateau.

From the intervening region an extension of the Yukon Plateau to the south, between the Yukon and Koyukuk rivers, forms the Yukon Hills, which are reported to attain a height of from 1,000 to 2,500 feet between the Koyukuk and Melozi rivers. As seen at a distance from the Koyukuk side, these hills give the impression of a comparatively even crest line or plateau-like top, having a somewhat great northeastward and southwestward extension, with a more or less gentle slope southward. Throughout most of the Koyukuk Valley, as will be shown later, erosion has carried the surface of the plateau to a much lower level, 1,200 to 1,500 feet being probably an approximate average elevation. Exceptions, however, occur, where detached groups of mountains, as the Batza, near the sixty-sixth parallel, rise to a height of nearly 4,000 feet.

CHANDLAR RIVER BASIN.

Course of the river.—The Chandlar River Basin, as shown on the map, may be said to head in the mountains in approximately 68° to 69° north latitude and 149° to 150° west longitude. From here its general trend is southeastward for 150 miles in a straight line to where the river flows into the Yukon. The distance along the valley, however, is much greater, by reason of heavy bends, and will considerably exceed 200 miles. The most pronounced of these bends, each of which forms about a right angle, are at Bend Mountain and Fish Creek, in the upper part of the valley, and below West Fork.

The topography of the basin is best considered in three sections, all more or less distinct. These are the mountainous section, the Yukon Plateau section, and the Yukon Flats section.

Mountainous section.—The first or mountainous section, extending from the head nearly to West Fork, may be characterized for the most part as a narrow, canyon-like valley whose floor is from 1 to 2 miles in width, with rugged mountains on both sides rising sometimes abruptly to a height of nearly 5,000 feet, or nearly 3,000 feet above the floor of the valley to the general level of the land mass of the region. The rocks composing these mountains are chiefly metamorphosed sedimentaries, quartzite-schists, mica-schists, and limestones. The tributaries of this section, which are nearly all of the short, gulch-like order, do not extend more than 10 or 12 miles back from the river on either side, so that the average width of the valley in this section nowhere greatly exceeds 25 miles.



A MOUNTAINS OF LIMESTONE AND MICA-SCHIST, NORTH SIDE OF ROBERT CREEK FROM HORACE PEAK (6,000 FEET), ON HEADWATERS OF KOYUKUK RIVER, 652 MILES ABOVE ITS MOUTH, LOOKING S. 65° W.



B VIEW UP CHANDLAR RIVER AND VALLEY FROM EDGE OF FLATS, 60 MILES ABOVE MOUTH, LOOKING N. 48° E.

The regions about the heads of both East and Middle forks also lie in the mountainous section of the basin, but both these tributaries after leaving it flow southward through the Yukon Plateau section for some distance before joining the main river. In the upper reaches of this mountainous section, near the sixty-eighth parallel and from here northward, the valley materially widens, and the river flows in sharp V-shaped, secondary canyons, cut to a depth of 100 feet or more in an older valley floor, which apparently owes its origin to base-leveling at a time when the region stood at a much lower level than now. For 30 or more miles above Chandler Lake considerable silting has taken place in the valley in comparatively recent times, probably due in part to damming by local glacial deposits about the foot of the lake. In this mountainous section, about 8 miles below the foot of the lake, occur also the Chandler Rapids (Pl. LXI, *A*), where the river crosses a low east-west anticline which probably marks at least one of the axial lines of uplift which, farther south, near West Fork and elsewhere, gave rise to the difference of level that marks off the mountainous belt from the Yukon Plateau section.

Yukon Plateau section.—In this section the basin extends from the edge of the mountains near West Fork through the Yukon Plateau to the edge of the Yukon Flats, a distance in a straight line of about 60 miles. Its trend is nearly eastward. The canyon-like valley of the mountain section has been left behind, and both the basin and the valley are very much widened and receive tributary valleys of considerable size from the north and from the west. The principal are those of East and Middle forks from the north.

At the big bend below West Fork an apparently old valley of considerable width and length comes in from the southwest. It is reported to head up against the head of a stream known by prospectors as Swift River, which drains in the opposite or southerly direction and must accordingly flow into Dall River or into the Yukon above the Dall.

The general elevation of the land mass, consisting of low mountains dissected out of the Yukon Plateau on either side of the river, is about 3,000 feet. The topography is more or less reduced and rounded. The plateau in general slopes southeastward. The rocks comprising it are granite, quartz-schist, mica-schist, slate, basalt, and probably some diabase. The surface slopes rather rapidly southeastward to where the edge of the plateau meets the Yukon Flats (Pl. LXIV, *B*), to which the descent is by one or more terraces. The rise from the valley to the plateau is usually gradual. This section of the valley contains a more or less continuous mantle of till or glacial drift, often represented by terraces or low bluffs 100 feet or more in height along the river.

Yukon Flats section.—This section includes that part of the basin lying in the Yukon Flats between the edge of the Yukon Plateau and

the mouth of the Chandlar River, a distance of about 50 miles in a straight line. Its lateral limits are indefinite, as it is not distinguishable from the Yukon Flats, and but few tributaries are received, all of which are very short and sluggish. These Yukon Flats are a part of the Pleistocene lake floor, outlined by Spurr¹ in his map of the Yukon gold belt. The surface of the deposit has the appearance of a dead level. The rise along the Chandlar River from its mouth at the Yukon to the edge of the Yukon Flats, however, is about 300 feet, with a current in the upper part very swift.

CHANDLAR RIVER.

The Chandlar River is about 250 miles long. It may be ascended about 200 miles by canoe, to some distance above Robert Creek portage, where the gradient becomes torrential. A short portage of about one-eighth of a mile, however, is necessary at the Chandlar Rapids, about 8 miles below the lake (see Pl. LXI), where the river, in crossing a rugged belt of bed-rock mica-schist, produces a rough stretch of water much less navigable than the White Horse Rapids below Miles Canyon on the Lewes River. Between Robert Creek portage and the head of Chandlar Lake, where the floor of the valley has been much silted up, the river in large part has a very winding course, and for the last 20 or 30 miles above the lake it meanders sluggishly through the old flood plain of silts and gravels, and can be ascended by rowing or paddling in canoes.

Through the lake the current is by estimate about one-half mile per hour. The lake is about 10 miles long and 2 miles or more in width. It is probably not deep, but is navigable for steamboats of considerable size. The basin containing the lake seems to owe its existence more to the damming up of the valley at the foot than to any configuration of the bed rock.

From the foot of the lake to the rapids, a distance of about 8 miles, the river is comparatively smooth. The rapids extend for about one-fourth of a mile, in which the fall is 10 feet or more, principally at the lower end, where a portage of one-eighth of a mile, as indicated, is necessary.

From the rapids to the great bend below West Fork the current is swift, with some riffles difficult to ascend with canoe. Almost the same is true throughout the Yukon Plateau section of the river and for about the upper half of its length through the Yukon Flats. In the flats, however, the riffles are composed of fine gravel, and the bed is not beset with large boulders, as is often the case in the plateau section of the river.

Almost throughout the flats the stream is commonly broken up by islands or bars into several or more channels. Finally, at its mouth, so

¹Spurr: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 253.



A. MOUNTAINOUS TOPOGRAPHY IN LIMESTONE, FROM FAULT MOUNTAIN (5,400 FEET), LOOKING S. 45° E.



B. VIEW OF MICA-SCHIST MOUNTAINS, LOOKING N 55° W. FROM FAULT MOUNTAIN WEST BANK OF DIETRICH RIVER

far as known, the river enters the Yukon by means of several diverging channels through a wide delta of silts and alluvium. During high water Chandlar River could probably be ascended with a flat-bottomed steamboat for 20 or 30 miles, but at ordinary stage for not more than 6 or 7 miles, if at all, on account of the riffles soon encountered.

Some idea of the volume of the river may be gained from the statement that for the lower 10 or 12 miles above the head of the delta, at places where the stream was apparently gathered into a single channel, it was found to average about 300 feet in width and about 6 feet in depth, and to have a velocity of about $4\frac{1}{2}$ or 5 miles an hour. Nearly all cross sections in this region revealed places where the bottom could not be reached with a 13-foot pole.

The two principal tributaries received by the Chandlar River are East Fork and Middle Fork (see Pl. LX). They are of about equal size, swift, and loaded with sediment. Their combined contribution approximates in volume that of the main river above Middle Fork. West Fork is also a stream of considerable size and enters the river at a steep gradient.

KOYUKUK RIVER BASIN.

The Koyukuk drains the northwestern part of the Yukon Basin. It is one of the largest tributaries of the Yukon, which it enters from the north about 450 miles above its mouth. It has a very large drainage basin, which, as already noted, heads to the west of the Chandlar Basin, in the Rocky Mountains, in the northeastern part of Alaska, in approximately 69° north latitude and 150° west longitude. From that point its axis trends southwestward through a distance of more than 300 miles toward the head of Norton Sound to the Yukon River near Nulato. The area drained is probably about 32,000 square miles. Near its upper part it has a width of about 150 miles.

The parallelism of the basin with the adjacent section of the Yukon, extending from Fort Yukon to the mouth of the Koyukuk, is very pronounced, as may be seen on any approximately reliable map.

On the northwest the basin is separated by a rather low and narrow divide from the drainage of the Colville, Noatak, Kowak, and other rivers, which drain northward into the Arctic Ocean and westward into Kotzebue and Norton sounds.

Like the basin of the Chandlar River, already described, the Koyukuk Basin, of which the Middle Fork is a good example, also in part lies in the rugged, mountainous belt (Pl. LXV, *A*) separating the Yukon drainage from that of the Arctic Ocean on the north. This mountainous section of the basin consists mainly in a canyon-like valley but a mile or two in width, into which open similar though smaller lateral canyons and gulches (Pl. LXV, *B*). In the region between Slate Creek and Tramway Bar the mountains begin to give way, and from here to the Yukon the basin lies in the Yukon Plateau,

whose general level is but 1,500 or 2,000 feet above the floor of the valley. The valley often attains a width of several miles, and not rarely for sections of considerable extent contains areas of flats (Pl. LXVI, *A*) resembling the Yukon Flats. The flats in the Koyukuk Valley, however, are not known to now have any direct geographic connection with the Yukon Flats or the basin of Lake Yukon, unless it be by way of the valley along the Yukon River. The Koyukuk Flats are, however, Pleistocene, and are contemporaneous with the Yukon Flats, but seem to have been deposited in water cut off from the lake of the Yukon Flats and in bodies of water or lakelets more or less disconnected. This can be determined only by further investigation.

In the upper, northwestern, part of the Koyukuk Basin the plateau is deeply marked by four or five tributary valleys of large size, most of which seem to head in the mountainous belt which apparently continues to skirt the basin in that region. Along the valley of the Koyukuk near its middle part, in the region of Red Mountain and



FIG. 22.—Profile across Koyukuk Valley above Red Mountain, showing old valley floor 750 feet above river.

below Bergman, are found remnants of an old valley floor at an elevation of about 750 feet above the present flood plain of the river. The benches of this old floor on either side of the river often vary in width from less than 1 mile to 2 or more miles (see profile, fig. 22), and give to the old valley floor a total width of 3 or 4 miles.

KOYUKUK RIVER.

Considering Dietrich River as the source of the Koyukuk, it apparently heads at about parallel 69° north latitude and east of 150° west longitude, giving to the river from this point to its mouth at the Yukon a length of approximately 700 miles. Throughout almost the whole of this distance, from near the sixty-eighth parallel to the Yukon, there are no rapids.

Dietrich River was ascended by the survey party to Fault Mountain, near the sixty-eighth parallel. This seems to be approximately the head of canoe navigation at the ordinary stage of the river, not owing, however, to insufficiency in the volume of water so much as to the distribution of the river into innumerable channels which thread the silted-up gravel floor of the valley. This condition prevails for 15 miles or more below Fault Mountain. A little above Fault Mountain the stream seems to improve and to be confined more nearly to a



A. VIEW OF FLATS ON MIDDLE FORK OF KOYUKUK RIVER LOOKING S. 60° W



B. GOLD-BEARING SCHIST SHOWING CLEAVAGE AND ATTITUDE OF ROCKS IN BED OF MYRTLE CREEK, LOOKING N. 60° E.

single channel for some distance. In this region the mountains rise from 2,000 to 3,500 feet above the valley.

The course of Dietrich River from its source for a distance of about 75 miles is nearly due south to the point where it unites with Bettles River, a stream similar to the Dietrich, coming in from the east and forming at its confluence with the Dietrich the Middle Fork of the Koyukuk (see Pl. LX). From the confluence of Bettles and Dietrich rivers the Middle Fork of the Koyukuk, receiving short tributary creeks from either side, continues southward with comparatively swift current in a generally narrow, canyon-like valley for about 30 miles, to the southern edge of the mountains, in the region of Slate Creek.

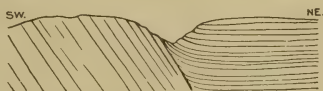


Fig. 23.—Faulting in sandstone below Bergman.

Here, upon entering the Yukon Plateau, the course of the river becomes southwesterly through a country whose topography is varied by low mountains, plateaus, and occasionally areas of flats, the latter sometimes of considerable extent. From Slate Creek to the sixty-seventh parallel, a distance of about 40 miles, the general elevation of the plateau surface or land mass will probably average about 2,800 feet. Just below the sixty-seventh parallel the mountains extending southward between the Middle and South forks attain some prominence, rising to a height of about 3,000 feet. From this point, however, to below the confluence of the Middle and South forks, near the Arctic Circle, the country between the two forks is principally flats. These flats continue for some distance south of the Arctic Circle.

Upon leaving the mountains below Slate Creek the river soon enters a zone of younger and softer rocks (Pl. LXVII, *B*), and the valley becomes wider and more open. At Tramway Bar, however, where a belt of harder conglomerate is encountered, the river flows through a narrow canyon whose steep walls rise about 100 feet above the river.

It is in the upper Yukon Plateau section of the river, between Tramway Bar and the Arctic Circle, that the Koyukuk receives nearly all its large tributaries. They come principally from the northwest and are nearly of equal size. Within a distance of about 75 miles along the river the North Fork, Hokotena, Totsenbetna, Fickett, and Allen rivers, all entering at points about equally distant, contribute, respectively, large volumes of water. They nearly all seem to head well back in the mountainous belt, and in length will probably average 100 miles. They have a comparatively steep gradient and a velocity of 6 miles or more an hour. At high water some of these streams have been ascended for a considerable distance by prospectors in flat-bottomed steamboats.

On the southeast side the only tributary of much note received in this section of the river is South Fork, a little above the Arctic Circle. At their confluence South Fork is by estimate about two-thirds the size of Middle Fork, or the main river. It heads in the high, rugged mountains between Middle Fork and the Chandlar River, in approximately $67\frac{1}{2}^{\circ}$ north latitude, near the one hundred and forty-ninth meridian. Its course for nearly 100 miles is southwestward, parallel with Middle Fork, to near the Arctic Circle, where, below Fish Creek, it trends westward about 25 miles and unites with Middle Fork. The two streams, in general, are only about 20 miles apart. South Fork is also reported to head in or be associated with lakelets in its upper waters. Along its course it receives numerous tributary creeks, some of which are of considerable size, especially on the southeast, of which the principal are Mosquito Creek, Jim Creek, and Fish Creek. For 100 miles or more southward from the Arctic Circle the velocity of the Koyukuk River is about 6 miles an hour.

Another tributary of considerable size is the Alashuk, heading in the northwest, near the head of the Noatak and Kowak rivers, which flow westward into Kotzebue Sound. The Alashuk enters the Koyukuk near the head of Waite Island, at about the sixty-sixth parallel.

For the first several hundred miles above its mouth the course of the Koyukuk River is very tortuous or winding, where it meanders over the flats with a velocity of scarcely 4 miles an hour. The only large tributary received in this lower region is the Huslia, which heads near the Selawik on the northwest. The latter flows westward into Kotzebue Sound.

The Koyukuk is a large river and carries a large volume of water. From the edge of the mountains near Slate Creek to the Arctic Circle near Bergman, a distance of 150 miles, the velocity will probably average about $6\frac{1}{2}$ miles an hour. From Bergman to the mouth of the river at the Yukon, a distance of 440 miles, the current is estimated at about 4 miles an hour, but in many places it is considerably less. The average width of the river in this section, excluding islands, is about one-third of a mile, or about 600 yards. Near its mouth, as noted by Allen,¹ the width is about 500 yards and the current about 3 miles an hour.

Its depth, its slow current, and the absence of rapids and riffles render the Koyukuk admirably navigable for flat-bottomed steamboats of moderate size from its mouth to Bergman. At the normal stage of the river Bergman may be considered as the head of steamboat navigation, on account of the bars, riffles, and swifter currents which begin a short distance above this point and the perceptible diminution in the volume of water above the mouth of the Allen. At

¹ Report on an Expedition to the Upper Tanana and Koyukuk Rivers, in the Territory of Alaska, by Lieut. Henry T. Allen, U. S. A.

high water, however, during early summer, steamboats ascend to above Tramway Bar, and during the seasons of 1898 and 1899 some of the larger northwest tributaries were ascended for a considerable distance by the steamboats of prospecting parties. The Allen is reported to have been thus ascended by steamboat for a distance of more than 40 miles above its mouth.

GEOLOGY.

GRANITE—PROBABLY BASAL.

Apparently the oldest rock seen during the exploration is granite. The first good exposure was seen on the south side of Chandlar River, about 4 miles west of the edge of the Yukon Flats and about $1\frac{1}{2}$ miles above the mouth of East Fork. Here it largely takes the form of a gneissoid granite, with a northwest-and-southeast structure trend and a northerly dip of 75° . The rock is considerably crushed and sheared and shows the effects of dynamic action. What seems to be the major jointing trends about north and south with a steep easterly dip. Macroscopically the more gneissic portion of the rock is evenly fine grained. Microscopically it is seen to be greatly sheared and crushed and to consist of quartz, orthoclase and plagioclase feldspar, biotite, and some hornblende. On fresh surfaces the rock is greenish gray in color, but it weathers brown. It is intruded by an apparently younger and fresher-looking granitoid rock, which in hand specimen is medium grained and more or less disposed to be porphyritic, with feldspar phenocrysts occasionally one-fourth inch in diameter. On fresh surfaces this intrusive rock has the appearance of a typical gray granite, conspicuously dotted and speckled by crystals and flakes of black biotite about one-sixteenth inch in diameter. Under the microscope it is found to have the constituents of a granodiorite, being composed of quartz, fresh orthoclase, plagioclase, biotite, and hornblende. This rock occurs as a dike in the gneissoid rocks. This is shown by the contact metamorphism and by its fineness of grain along the contact, where also a graphic granite structure to some extent has originated. This structure is radially disposed and dies out with recession from the contact line.

The gneissoid rock is also cut by narrow or thin acidic aplite dikes. The aplite is of a light-gray color, very fine and even grained, and microscopically is seen to consist of quartz and feldspar, with a very small amount of green, apparently chloritic, mica. These dikes much resemble those of the Fortymile district, described by Mr. Spurr.¹

Eastward this gneissoid rock seems to extend to the edge of the Yukon Plateau at the flats, where olivine-basalt appears to rest upon

¹Geology of the Yukon gold district, Alaska, by J. E. Spurr: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 229.

it. The actual contact of the basalt and granite was not observed, on account of the covering of talus and moss, but the presence of large angular boulders of the granite on the slopes only a short distance below the exposures of the basalt in place seems to leave little doubt concerning the relations of the two rocks.

Westward along the south edge of the river the granite has a known extent of 25 miles, and it may extend 8 or 10 miles farther to Granite Creek Valley, where it gives way to a series of metamorphic sedimentary rocks. Judging from the observations, that part of the Yukon Plateau lying between the Chandlar River and the Yukon Flats on the south and extending from the edge of the flats at the river westward to Granite Creek, a distance of about 40 miles, is largely composed of this rock. The granite may occur also on the north side of the river, especially in and below the region of East Fork; this was not visited, however, on account of the difficulty of access and want of time. As the rock weathers brown and is nearly always densely coated with lichens, where not covered with moss, its character could not be satisfactorily determined from a distance, even with the field glass. Topographic criteria were found to be of some aid, but were not satisfactory.

Westward along the river the rock occurs in more or less broad ridges. In the western part of the known granitic area it continues as the dominant rock of the Yukon Plateau, which here rises to an elevation of about 3,500 feet, or about 2,000 feet above the floor of the valley. Here the rock is sometimes so highly sheared and altered as to partake much of the nature of a granitic mica-schist. In some zones it can not be distinguished macroscopically from a true biotite-schist, and it is often somewhat folded, jointed, and cleaved. Here in general it is medium to rather fine grained, and except in the more micaceous zones is highly acidic. It is cut by some pegmatitic and aplitic dikes and seams. The pegmatite dikes sometimes carry conspicuous crystals of black hornblende. The general structure of the schistosity trends northwest and southeast, with steep northeasterly dip. Trending with the schistosity occur a few nearly white quartz veins, the largest of which is about 2 feet in thickness, but so far as observed the quartz is not mineralized to any great extent.

From the highly sheared and schistose condition of the granite it is inferred that it may probably be basal, or the oldest rock found in the field. It resembles the basal granite of the Fortymile district, as described by Spurr.¹

AMPHIBOLITE-SCHIST.

This rock was seen only in the bottoms of the valleys near the headwaters of both the Chandlar and Koyukuk drainages and in one other

¹ *Op. cit.*, p. 135.

locality. Judging from its apparent position in the geologic horizon it ranks among the older rocks in the field. It is apparently younger than the Rapids schist, just described, and it seems to occupy a lower horizon than the Lake quartzite-schist, which may provisionally be referred to the Birch Creek series. It is a fine-grained fissile or fibrous schist of apple-green color. It occurs on Chandlar River about 3 miles above Bend Mountain. Here it is not, as usual, restricted to the floor of the valley, but seems to be the conspicuous rock in a mountain of moderate size known by the prospectors as Green Mountain. Along with gray mica-schist and limestone it forms the mountainous slope fronting the valley on the north. Back of this front it seems to have a somewhat wider extent to the northward. At the base of Green Mountain, near the edges of the valley, the schistosity trends northeast and southwest, with dip gently northwestward. Here it is found to be very siliceous and to partake largely of the nature of a micaceous quartz-schist. The quartz, however, is disposed in small bands and veinlets, all of which have suffered flexing and folding, the small folds often occurring in the most recumbent manner. The presence of sulphides, and occasionally carbonates, denotes mineralization. Assays of the contained quartz show it to carry both silver and gold, a fuller account of which is given under the heading "Mineral resources," on page 485.

In the floor of the valley a few miles below Portage Creek the schist forms a low bench of some prominence, whose surface is about 25 feet above the present level of the river. It was next met with on Robert Creek, at about the same elevation as on Chandlar River, to the northeast of Horace Mountain, where it exclusively forms the low bluffs and benching along the northeast side of the creek. It occurs also in Robert Creek Canyon. On Dietrich River, at about 5 miles below Fault Mountain, on the north edge of the valley, it again forms a low bench rising to about 20 feet above the river. The trend of the schistosity here is northeast and southwest, with a dip of about 35° southeastward. Here the rock also has a pitch or plunge structure, with a dip of about 20° southeastward. A couple of exposures of limited extent were also met with at the base of the mountains along the Middle Fork of the Koyukuk River, between Bettles River and Slate Creek. Here gray micaceous quartzite-schist, probably referable to the Birch Creek formation, seems to rest upon it.

RAPIDS SCHIST.

This term refers to a narrow belt of highly metamorphosed or altered mica-schist traversed by the Chandlar River in the region of the rapids, where the schist forms a low anticline, with much quartz, in the bight of the fold. Here the rock embracing the rapids extends

for several miles downstream nearly to West Fork. This rock in geological horizon is supposed to lie next to the basal granite. It seems to underlie the Lake quartzite-schist, but may prove to be a lower member of this series, so altered by metamorphism as to bear little resemblance to the general type to be next described. In the region of the rapids, and to some extent below, the rock is a biotite-schist, closely appressed or crowded into numerous short folds, and contains much quartz, some garnet, and other metamorphic minerals.

The trend is east and west. At a short distance below the rapids the dip is southward, while above the rapids it soon becomes northerly.

The rock was noted only along the river and does not seem to ascend high into the mountains. From its mineralized character it would ordinarily be regarded as one of the most auspicious to be examined for mineral resources.

On the Middle Fork of the Koyukuk, at the mouth of Bettles River, occurs a small area of what appears to be much the same rock. It here passes with southerly dip beneath the heavy-bedded limestone of this region.

LAKE QUARTZITE-SCHIST.

This rock is here called the Lake quartzite-schist because of its great prominence at Chandlar Lake. In the bend of the lake it forms a steep-faced cliff, rising nearly 2,000 feet above the lake, offering a fine exposure of structure and jointing. It seems probable that with future examination this rock may be correlated with the Birch Creek schists, studied and described by Mr. J. E. Spurr in his report on the Yukon gold district.¹

Geologically this rock overlies the Rapids schist, and it apparently underlies the limestone series on the northwest. In distribution it seems to extend from near the West Fork of Chandlar River northward to beyond the lake, and from east of Chandlar River westward to the Middle Fork of the Koyukuk. It is apparently one of the chief rocks constituting the rugged mountainous mass in the above area, rising to a height of nearly 6,000 feet.

From near the West Fork of Chandlar River to near the rapids the dip is southerly; but above the rapids, near the head of the lake, it becomes gently northwestward, the divergent dips apparently denoting the two sides of an anticline, the rock being thus more or less conformable with the Rapids schists previously noted.

So far as observed the rock is principally a micaceous quartzite-schist, though in some localities the mica becomes the dominant essential mineral. The quartz grains are usually rolled and rounded, denoting a sedimentary origin. Besides biotite, which is usually greenish, some muscovite and chlorite also occur. Magnetite as an accessory is often present in considerable amount. Garnet has been

¹ Eighteenth Ann. Rep. U. S. Geol. Survey, Pt. III, p. 141.

sparingly noted. In some instances the minerals are considerably crushed, and the foils of biotite bent and flexed about the quartz. In other cases there is present considerable graphitic material, giving to the rock occasionally the aspect of a graphitic schist. The rock carries some quartz veins of moderate size, trending usually parallel with the schistosity, while some deviate or run nearly at right angles to it. A few exhibit mineralization, though this is not pronounced. At about 3 miles south of the head of Chandlar Lake the rock is cut by a greenish dioritic dike several hundred feet in thickness, which has a northeast and southwest trend.

BETTLES SERIES.

This name is here provisionally used on account of the excellent exposures of the rocks afforded on the lower part of Bettles River, where the mountains which they compose rise steeply 2,000 feet or more above the river. The rocks consist of a series of heavy-bedded limestone, with more or less interbedded mica-schist. The limestone or marble is usually banded and schistose, but sometimes occurs comparatively massive. It is usually of light or impure white color, and is frequently mottled with stains of a reddish mineral, probably hematite.

This series forms the principal capping rock over an extent of country embracing apparently an area of about 2,000 square miles on the upper waters of the Chandlar and Koyukuk rivers. Its geologic relation to the lake quartzite-schists would place it in a higher horizon, and it may with future examination be correlated with the Fortymile series of the Yukon, described by Mr. Spurr.

The rocks are considerably folded and greatly faulted on the Chandlar, Bettles, and Dietrich rivers. They are also cut by pronounced jointing and numerous well-marked cleavages. This faulting is perhaps best shown on the south side of Bettles River, where the dislocation by fault contact with the schist on the east is very pronounced. It is well marked also in the region of Fault Mountain, on Dietrich River.

The dip of the rocks on the Chandlar River side is northwestward, while on Dietrich River, on the Koyukuk side, it is southerly.

The topography formed by this limestone is the most rugged met with throughout the season's work. It is shown in Pls. LXIII, *B*; LXIV, *A*; and LXV, *A*, of which latter it forms but a part of the topography. In the two former plates the rock is seen forming the dissected surface of the high, mountainous plateau.

WEST FORK SERIES.

This series of rocks, of which but little was seen, so far as known, crosses the Chandlar River Valley in a belt about 15 miles in width, from below Granite Creek to above West Fork. The series, however,

in all probability, if understood, has a very much wider distribution. It seems to rest unconformably against the basal granite on the south-east and to overlie the lake quartzite-schists on the northwest. The dip, so far as observed, is southeasterly at an angle of about 40° .

These rocks, which are only partially schistose, consist of fine-grained, dark-gray quartzite, dark flint, calcareous black shale, and impure limestone. The series is cut or intruded by dioritic and greenish di-basic dikes, which have a northeast-and-southwest trend, with the structure of the rocks. The dark quartzite, and especially the black flint above referred to, bears a marked resemblance to the fossiliferous black flint found in the gravels below East Fork. The fossils in these gravels have been determined by Dr. Girty, of the United States Geological Survey, as certainly Paleozoic and probably Devonian. A list of the fossils, as determined, will appear in a later report. It is therefore suggested that the West Fork series may be Paleozoic.

The trend of the series across the country to the northwestward would include in the belt the rocks about the head of East Fork, whence the Paleozoic gravels seem to have been derived.

Southwestward the series apparently occurs on the South Fork of the Koyukuk, in the region of Jim Creek, where it was noted and where specimens were collected by Mr. D. C. Witherspoon, in charge of the South Fork detachment of the party. Here also the rock is fossiliferous, containing the same Paleozoic forms as the black flint gravels below the East Fork on the Chandlar River. It may also be noted that the trend of this series, continued still farther northeastward beyond the Chandlar River East Fork region, would strike the lower ramparts of the Porcupine, where Mr. McConnell, of the Canadian Geological Survey, reports the limestone to yield fossils referable, in part at least, to the Devonian.¹

The topography throughout the belt, especially to the southeast of Chandlar River, has been much reduced, giving a marked contrast between that of the Yukon Plateau, formed by these rocks, and that of the higher and more rugged mountainous type, formed by the Lake quartzite-schist, to the north.

LOWER CRETACEOUS.

Apparently the next succeeding geologic horizon met with is the Lower Cretaceous. It is found near the middle part of the Koyukuk River Basin, along the Koyukuk River, where it is known to extend from about 10 miles north of the sixty-sixth parallel, or about 15 miles north of Waite Island, southwestward for a distance of 30 or more miles, to where the river makes a pronounced northwesterly bend, which course it follows for some 40 miles.

¹ Ann. Rept. Geol. Survey Canada, new series, Vol. IV, 188-189, p. 133 D.



A. SLUICING GOLD PLACERS BY ELSINGSON PARTY ON MYRTLE CREEK, LOOKING UPSTREAM,
N. 20° E



B. YOUNG ROCK SERIES OF SANDSTONE AND CONGLOMERATE WITH SOME LIGNITE, LOOKING
N. 65° W

The rocks consist of impure limestones bearing a fauna which has been determined by Dr. Stanton as Lower Cretaceous. The limestone is often of a pink or reddish color, and usually dips northeastward at an angle of about 40° . It is frequently associated with igneous amygdaloidal rocks and sometimes with tuffs of andesitic nature. These igneous rocks apparently denote volcanic activity during Cretaceous times. The extent of this formation may be very much greater, but exposures of it were not observed away from the river.

UPPER CRETACEOUS.

South of the Lower Cretaceous localities, fossils found in an impure limestone, sometimes arenaceous, were determined by Dr. Stanton as characteristic of the Upper Cretaceous.

KENAI SERIES.

On the Middle Fork of the Koyukuk, about 5 miles above Tramway Bar, the metamorphic rocks give way to a younger rock series composed of impure sandstones, arkose, grit, and conglomerate, indiscriminately carrying more or less lignite and remains of fossil plants. On account of its fossil contents and its resemblance to the Kenai found elsewhere in the Yukon district, this formation is provisionally referred to the Kenai, which is regarded by Dr. Dall as Upper Eocene. In some localities the beds are quite firmly consolidated, especially the sandstones, while in others they are sufficiently soft to be readily plucked away with a pick or hammer. In nearly all localities the beds show more or less disturbance and some faulting and folding. Above Tramway Bar they have a southerly dip, as shown in Pl. LXVII, *B*. At Tramway Bar they consist of a belt of firmly consolidated conglomerates, 3 or 4 miles wide, through which the river has cut a canyon about 80 feet deep.

From Tramway Bar to below the Arctic Circle frequent exposures of sandstone, soft shale, and mud rock, carrying more or less imperfect plant remains, are met with. These rocks are probably principally Tertiary and are apparently younger than the Kenai series. Their attitude often varies, and they nearly always show more or less disturbance.

Judging from the occurrence of lignite and materials resembling the Kenai contained in the Pleistocene deposits of till in the Chandlar River Valley, it seems probable that the Kenai may also occur in this valley, though no exposures of it were observed in place. This inference is based principally on the belief that the till is of local origin and that its materials have been derived from within the Chandlar Basin.

NULATO SANDSTONE.

The Nulato sandstone is exposed principally along the Yukon River, between the mouth of the Koyukuk and Nulato, where it has been described by both Dr. Dall and Mr. Spurr. It probably also covers a considerable area in the lower part of the Koyukuk Basin, near the mouth of the river.

Along the Yukon the dip of the Nulato sandstone is principally gently northwestward, but toward Nulato the dip increases.

PLEISTOCENE.

Till in Chandlar Valley.—From the edge of the flats westward, principally in that portion of the Chandlar River Valley occupying the plateau section of the country, occurs an apparently more or less continuous sheet of unconsolidated Pleistocene deposits, which was found on examination to be till. Along the river it often forms bluffs about 100 feet high, and on the south side of the valley, opposite Flat Creek, it was found at a height of about 2,200 feet. It is composed of heterogeneous materials, but substantially all, so far as observed, may have been derived from within the Chandlar River Basin. The bowlder clay has a sandy matrix, usually yellowish or buff-colored. The gravels range from fine pebbles to bowlderets, and sometimes bowlders of considerable size. As already noted, the till also contains a considerable quantity of lignite, supposed to have been derived from the Kenai formation. In the mountainous section of the river below the rapids the drift in some localities is disposed in ridges of coarse bowlders, trending north and south with the direction of the valley.

River gravels of Upper Koyukuk.—On the upper part of the Middle Fork of the Koyukuk, where it crosses the parallel of $67\frac{1}{2}^{\circ}$, just above the mouth of Nelson Creek, a deposit of Pleistocene river gravels is first encountered in descending the river. These gravels form more or less argillaceous bluffs rising 30 to 60 feet above the river, and apparently denote the bed of an old river channel, cut when the land stood at a lower level than at the present time. From this point southward they occur more or less continuously throughout the mountainous section of the valley.

Bench auriferous gravels of Tramway Bar.—On the plateau-like surface of the conglomerates through which the river has cut its canyon at Tramway Bar lies a deposit of coarse gravels which for some time have been known to be auriferous. They apparently represent the deposits in the bed of an old river channel which was occupied by the stream before it began its down-cutting in the present canyon of Tramway Bar. These gravel deposits may have been contemporaneous in deposition with those above alluded to, in the mountainous section of Middle Fork. They range from fine gravel to bowlderets and



A. SILT BLUFFS, ON KOYUKUK RIVER NEAR ARCTIC CIRCLE, LOOKING EAST



B. VIEW UP KOYUKUK RIVER, SHOWING LOW ROLLING PLATEAU BLUFFS ETC., 173 MILES ABOVE MOUTH OF RIVER LOOKING N. 30° E.

bowlders 9 inches or a foot in diameter. So far as observed, they seem to have a considerable extent westward, at least for a mile or more.

Lacustrine silts and gravels of Yukon and Koyukuk Flats.—The Pleistocene deposits forming the Yukon Flats have been somewhat extensively considered by Mr. Spurr, and require but little notice here. On the Chandlar River they extend from the Yukon River to the plateau section of the river, a distance of 40 miles in a straight line. Along the lower part of the Chandlar River the deposits consist almost exclusively of fine silts, the banks rising perpendicularly to a height of 10 or 15 feet above the river. Toward the edge of the flats, however, in ascending the stream the deposits become more gravelly, the gravel growing continually coarser as the edge of the Yukon Plateau is approached.

In the Koyukuk Basin deposits of a nature somewhat similar to those of the Yukon Flats are seen, which seem also to be of lacustrine origin. They are inferred to be so from the extreme fineness of the silts, the occasional perfect horizontality and evenness of the stratification, and the shell remains of *Succinea chrysis* which they contain. The deposits were nowhere traced continuously along the Koyukuk River, but were found presenting good exposures at disconnected points. They sometimes form bluffs with fresh, almost vertical faces, rising from 100 to 200 feet above the river. An example of the bluffs is shown in Pl. LXVIII, A. These silts on the Koyukuk occur considerably above the Arctic Circle.

RECENT STREAM GRAVELS.

This term is applied merely to the gravels and detritus being deposited by the streams at the present time. On both the Chandlar and the Koyukuk at high water the streams spread over a valley floor sometimes a mile or more in width, upon which a considerable sheet of gravel and detritus is deposited during the flood period. Upon the recession of the stream to its more normal stage and limited channel, this sheet appears as a waste of detritus. On the lower waters of the Chandlar and Koyukuk rivers at low water the inner side of the large bends of the rivers is occupied by such extensive wastes of gravel.

IGNEOUS ROCKS OTHER THAN THOSE DESCRIBED.

DIABASE ON CHANDLAR RIVER.

This rock was observed at but a single point. It may, however, occur in considerable amount along the northern side of the Chandlar River Valley. It is well exposed a few miles above the mouth of Middle Fork, on the north side of the river. Here it rises in prominent hills or low mountains to a height of about 1,000 feet. It is a

very heavy, greenish, dark or nearly black rock, much of it ferruginous, carrying considerable magnetite. It is cut by prominent east-and-west jointing which has a northerly dip of about 40° . Two other minor sets of joints are present, and one or more cleavages. The rock on the whole is considerably crushed, and has the appearance of age. It is seen under the microscope to consist essentially of plagioclase, with considerable augite and some olivine, while accessory magnetite is present in considerable amount. There is also a little quartz. In some cases serpentinization has taken place to a marked extent.

GRANITE ON BABY CREEK.

The rock referred to under the above name is prominent in the mountains just north of Baby Creek, on the Chandlar River, where it trends southwestward and northeastward toward Bend Mountain. Judging from observations made in the region of Chandlar Lake and from the granite boulders found in the Chandlar Valley in the region of the rapids and below, the rock probably forms a prominent part of the divide trending from West Fork northward to Bend Mountain. It is also supposed to continue northward beyond the Chandlar River in the Bend Mountain region.

It is a light-colored rock, with greenish tinge, of medium grain, and is considerably sheared or schisted. It has received but a cursory examination, from which it seems to be a granodiorite. It is composed of orthoclase and plagioclase feldspars, with some quartz, hornblende, and green biotite.

DIORITIC ROCK OF HORACE MOUNTAIN.

On the Koyukuk side of Robert Creek portage, opposite the mouth of Sheep Creek, the upper 1,000 feet or more of Horace Mountain is composed principally of a greenish-gray, speckled, igneous rock, which is apparently a large dike intruded into the schist series of this region. This is inferred from the completely altered condition of the country rock along the zone of contact, sometimes 100 yards or more in width. This was best observed on the northern slope of the mountain. The trend of this intrusive rock is northeast and southwest. From Horace Mountain southwestward for a distance of 10 miles it seems to form a somewhat prominent line of rugged peaks rising to a height of nearly 6,000 feet. From the same point northeastward it extends across Robert Creek in the direction of Geroe Creek and Bend Mountain, on the Chandlar River.

The rock in its different phases seems quite different from anything elsewhere met with on this trip. In its various stages it seems to show passage by dynamic action from an augite-diorite to an amphibolite-schist. In structure it varies from a medium-grained, some-

what gneissoid rock to a schist. The southeastern slope of the mountain is traversed by a more or less mineralized belt one-fourth of a mile wide. Here the rock seems to consist principally of quartz. It is greatly crushed, sheared, and folded, and stained a bright red. The staining material has not been examined in detail, but is probably hematite.

CRETACEOUS LAVAS.

These rocks can not here be taken up in detail. It may be well, however, merely to state that in the middle part of the Koyukuk Valley the intrusion and association of diabasic, andesitic, basaltic, and amygdaloidal rocks, and the association of tuff with the fossil-bearing Cretaceous strata, seem to denote considerable volcanic action during and subsequent to Cretaceous time.

TERTIARY LAVAS.

Basalt of Koyukuk Mountain.—At the mouth of the Koyukuk River on the Yukon, the sandstone and conglomerate considered Miocene are intruded by Tertiary lavas which are thought by Mr. Spurr to be post-Miocene, but still Tertiary. The intruded lavas at this point largely form the prominence known as Koyukuk Mountain, referred to by Dr. Dall in his Resources of Alaska, and later described and figured by Mr. Spurr in his report on the Yukon gold fields.¹ The mountain rises about 800 feet above the river. This lava has been determined by Mr. Spurr to be an olivine-basalt. The same lava seems to be intruded into the sandstones for some distance east of Koyukuk Mountain, where it rises somewhat abruptly, forming what is known as Elephant Mountain, about 2 miles above the mouth of the Koyukuk.

Southwestward the intrusive Tertiary lavas are known to occur more or less continuously between Nulato and St. Michael along the Yukon River. Also, at various points along the Koyukuk River exposures of black basaltic lava are frequently met with, which is probably largely of Tertiary age. This lava seen in outcrop is sometimes glassy, while the river gravels in the middle part of the Koyukuk Valley were found to carry cobbles of obsidian or true volcanic glass.

Basalt on Chandlar River.—Where the Yukon Flats meet the edge of the Yukon Plateau on the south side of the Chandlar River, as shown in the left of Pl. LXIV, *B*, the capping rock of the plateau, as already noted, is a black olivine-basalt, apparently resting on an eastward extension of the basal granite. This basalt, which seems to be a surface flow, is probably Tertiary or later. Its contact with the granite was not observed, on account of the covering of talus and moss. Its extent was observed 5 miles westward along the Chandlar River, where it

¹Geology of the Yukon gold district, Alaska. Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, p. 45.

gives way to the granite. Southwestward, however, it may have a considerable extent, probably forming in this direction the edge of the plateau, as at the river. It is supposed to occur also on the north side of the river at the edge of the plateau, but was not visited there.

MINERAL RESOURCES.

As the region is remote and comparatively new, much of it having never before been explored, only the most general statement of mineral resources can here be made.

COPPER.

The only indications of copper on the Chandlar River seen by the writer were detached fragments, apparently of quartz veins, carrying, with iron pyrites, copper pyrites and malachite, and a trace of bornite. Such specimens were found sparingly in the gravels above Chandlar Lake. Some also seen in the hands of prospectors were reported to have been collected on Mineral Creek, at the head of the lake on the southwest. On the East Fork Prospector Funcheon is reported to have found a ledge, samples of which assayed enough in copper to render it of commercial value if the occurrence is in sufficiently large quantity and the ore accessible.

On the Koyukuk River the indications seem to be much the same as on the Chandlar, the occurrences being on the headwaters of the upper tributaries heading in the mountainous limestone belt.

LEAD.

Galena is known to occur in the Bettles limestone on the upper waters of both the Chandlar and the Koyukuk. It is also reported on the East Fork of Chandlar River. Specimens were seen from Bettles River. Some reported to be from the upper part of the Hokotena were presented to the writer by Mr. Windrick at Peavey. In this instance the galena is associated with or partly incloses quartz crystals five-eighths of an inch in diameter and an inch or more long. On the eastern side of the divide, between Middle Fork and South Fork, opposite the head of Wiseman Creek, a limestone mountain of considerable size is reported by prospectors, in which galena is said to occur in large quantity.

GOLD.

Gold is not known to have been prospected for on the Chandlar River before the season of 1899. In ascending the river the gravel was occasionally panned by the writer and colors were found at a few points. The only prospectors by whom the river is known to have been visited are the four met at Chandlar Lake in 1899. These

men had entered the region by the overland trail from Fort Yukon, arriving at the lake early in March with a two-years' grub stake. They reported that they found light prospects and colors of coarse gold on several tributary creeks between Chandlar Rapids and the lake, though nothing rich had been encountered. These men were hopeful of the country and were prepared to extend their investigations. The prospects found seem to have been derived in large measure from the Lake quartzite-schist, whose hypothetical correlation with the Birch Creek schist has already been suggested.

On the Koyukuk River placer gold has been known for some time—since the early nineties, if not before. One of the earliest known occurrences is at Tramway Bar, above the sixty-seventh parallel, about 570 miles above the mouth of the river by boat. This has been referred to by Allen and Spurr. The gold was first discovered on the Koyukuk in the bars of the river, of which the most noted seem to have been Hughes and Florence bars. The Tramway Bar diggings, however, are bench placers, consisting of deposits of auriferous river gravels resting on a bench of apparently Kenai bed-rock conglomerate and sandstone at about 80 or 100 feet above the level of the river. The gravels are generally coarse, consisting largely of rolled cobbles and pebbles of quartz-schist and the older classes of rocks composing the mountains to the north. Several attempts seem to have been made to work these deposits, but thus far with no great success, owing probably to the remoteness of the region, the difficulty of transportation, and the lack of capital to provide water supply, which could readily be drawn from the river above, or possibly from lakelets said to occur to the westward.

The gold region of the Koyukuk River, as known at present, is roughly contained between the Arctic Circle and the sixty-eighth parallel and meridians $149\frac{1}{2}^{\circ}$ and 154° , west longitude. Diagonally across this area the gold belt, approximately 100 miles in width, embracing most of the tributary streams, follows the trend of the Koyukuk River southwestward. It is only in certain localities in this area, however, that gold placers have been found, and in only a few of these is the gold known to occur in paying quantities. The formations on which these placers lie are the Lake quartzite-schist, the West Fork schist, and the Kenai series, but whether any or all of these formations is the original source of the gold can not yet be stated.

The principal diggings when the region was visited by the writer last August (1899) were those of Slate Creek and Myrtle Creek, along the zone where the Lake quartzite-schist gives way to the West Fork series on the south. This, as will be noted, is also along the line where the mountains meet the Yukon Plateau. Here in the month of March, 1899, coarse placer gold in paying quantities was discovered on Slate Creek, an east-side tributary of the Middle Fork of the Koyukuk, which it enters 16 miles (approximately) above Tramway Bar.

The discovery was made by members of the Dorothy party, commonly known as the "Dorothy boys," from Boston, Massachusetts.

The country rock is principally mica-schist and slate. It is uplifted and stands on edge, while the gold occurs as shallow creek and gulch diggings. It is found principally on or near bed rock, in the jointings, fissures, and cleavage crevices. The gravels rarely exceed $3\frac{1}{2}$ feet in thickness. The diggings begin about 9 miles above the mouth of the creek, at the confluence of the two main forks, of which the north one is known as Myrtle Creek and the south one as Slate Creek proper. From this point they extend up to the head of Myrtle Creek, a distance of 5 or 6 miles, and up Slate Creek considerably farther. At the time the region was visited by me, in August, 1899, but little mining, beyond development work, had yet been attempted. Two mining districts had been organized, known as Slate Creek and Myrtle Creek districts. Most of the season was devoted to bringing in supplies and building cabins preparatory for winter. Sluicing had been begun on but two claims, one of which, on Myrtle Creek, reported the gravel as yielding from \$60 to \$80 a day per shovel. The gold is clean looking and coarse. It is considerably rolled, or flattened, and shows travel. The largest nugget taken out had a value of nearly \$20. The benches along these creeks are also found to be auriferous and are reported to prospect from 3 to 5 cents per pan.

In August there were reported to be 75 men at the diggings. A score or so others were on their way, many from along the South Fork, where they had been working with only moderate success during most of the summer. By estimate, there are probably 100 men now wintering (1899-1900) in the region. The principal supply post for the region is Bergman, near what was formerly known as Arctic City, 440 miles by river above the mouth of the Koyukuk and 146 miles from the diggings. This post is supplied principally by the Alaska Commercial Company, but is owned by and in charge of Pickarts, Bettles & Pickarts. It is practically at the head of steamboat navigation on the Koyukuk. A nearer post is Peavey, 104 miles below Slate Creek. Here are located a United States post-office, a United States land-office, and a store, but at present the place is not stocked with the staple articles of provisions needed by the miners. The establishment of a post at the mouth of Slate Creek during the coming winter is proposed by Pickarts, Bettles & Pickarts, who had much freight en route for the purpose. The principal summer route into the region is up Koyukuk River by flat-bottomed steamboat. In winter the region may be best reached by the trails leading overland from the Yukon near Fort Hamlin by way of Dall River, or from Fort Yukon by way of Chandlar River. Placer gold is known to occur over a somewhat wide range of country in the Koyukuk region, but, like that at Tramway Bar, the most of it may require capital to work the gravels. The placers on

Slate and Myrtle creeks are the only known rich diggings seen by members of the Survey. Late in August, 1899, word was received at Bergman that rich prospects had recently been found in a region known to the miners as Rocky Bottom, on the upper waters of Allatna or Allen River, a large tributary to the Koyukuk, which it enters from the northwest about 10 miles above Bergman.

Gold was also reported to occur on Wiseman, Marion, Porcupine, Twelvemile, and Pasco creeks, and on several of the larger northwest tributaries of Middle Fork. During the season of 1899 considerable mining was done on various tributaries of South Fork with fair success. On Rail Creek and some other of the smaller tributaries below Bergman, gold has also been found and the deposits have been worked to a small extent.

The Slate Creek gold is probably derived from the Lake quartzite-schists. These schists are traversed by quartz veins of considerable size, but the larger veins are not known to carry gold. A secondary series of smaller veins or veinlets and small lenticular quartz bodies or leaflets contained in the schist are apparently to some extent auriferous.

Of the quartz specimens collected, however, those yielding the best assays were from near the base of Green Mountain on Chandler River, the yield being about 0.42 ounce gold and 0.14 ounce silver per ton, or a money value of about \$8.50 per ton. All specimens assayed showed at least a trace of gold.

Recently (April, 1900) word has been received from the interior of the Koyukuk region that strikes have just been made on McKinley and Bryan creeks, small streams which are said to head in a range of low hills on the south side of the mountains. They are reported to have a pay streak of considerable width and are being worked by fifty or more men. Early in the sledding season of 1900, prospectors from numerous camps on the Yukon are reported to have started for these diggings, most of them taking their supplies with them by dog sled overland from Fort Yukon.

COAL.

The only indications of coal seen on the Chandler River were isolated fragments of tree stems, etc., found in the Pleistocene drift.

On the Koyukuk, in the supposed Kenai formation, lignite in small amount is common in the sandstones, grits, and especially in the conglomerates. The best occurrence is just above Tramway Bar, where a bed of it is nearly 12 feet in thickness, the middle 9 feet being comparatively pure lignite. The test, however, does not indicate the probability of its proving to be of much commercial value.

In the Nulato sandstone, on the Yukon, coal mines have recently been opened at several points a few miles above Nulato. Of these the

principal is Pickart's coal mine, about 10 miles above Nulato. Coal is found here in considerable quantity. It is a lignitic coal, but it is comparatively well metamorphosed and is shown, both by test and practical experiments, to be a good steaming coal, comparing very favorably with good steaming coals of Indian Territory and other regions in the Western States. It is being used to a considerable extent by companies operating steamboat lines on the Yukon River. One ton of the coal is reported to more than equal two cords of wood. Similar coals are also receiving considerable attention at other points farther up the Yukon, both above Circle City and at Cliff Creek, where the coal is mined in comparatively large quantity by the North American Transportation and Trading Company.

APPENDIX.

LATER CONDITIONS ON THE UPPER KOYUKUK.

As this report goes to press (December, 1900), authentic information is received of further discoveries of paying gold placers on the upper waters of the Koyukuk, mostly on tributaries of the Middle Fork. Of these the principal are Clara Creek, about 3 miles above Slate Creek, on the same (east) side of the river; Emma Creek, on the other (west) side of the river, just opposite Marion Creek; and Gold Creek, on the east side of the river, about 10 miles above Marion Creek. The Emma Creek gravels are reported to be very rich. Both here and on Gold Creek the ground is said to be all staked.

The principal supply post for the region is Bettles, located about 30 miles above Peavey, on the west bank of the river, near the sixty-seventh parallel.

ALASKAN GEOGRAPHIC NAMES

BY

MARCUS BAKER

ALASKAN GEOGRAPHIC NAMES.

By MARCUS BAKER.

Much confusion has existed, and to some extent still exists, respecting the geographic names in Alaska. These names, of various origins, come chiefly from Russian, English, and native sources. A few come from Spanish and French sources.

When the United States Board on Geographic Names was created, in 1890, one of its earliest efforts was to agree upon the spelling to be adopted for the names of some of the more important features in Alaska as to which prevailing usage was divided. It soon appeared that nothing short of a general examination and revision of all the names would yield satisfactory results. Accordingly the preparation of a card catalogue of the names was begun. Names of features in southeastern Alaska were carded at the office of the Coast and Geodetic Survey, under the direction of Mr. H. G. Ogden, and names in the remaining part of the Territory were carded by the writer. Some 5,000 names were thus carded, and the systematic writing up of these names in form for publication as a dictionary of Alaskan geographic names was carried forward as far as the letter F. This work, done at irregular and broken intervals, made slow progress and finally came to a standstill in 1896. Since that date there has been great activity in Alaskan exploration and survey and several hundred new names have appeared on the maps. Accordingly the Director of the United States Geological Survey has authorized the writer to resume work upon and to complete this dictionary.

In the present (Twenty-first) Annual Report of the Geological Survey are three papers on Alaskan topics. Several maps accompany these papers. The names appearing on these maps are here printed in dictionary order, accompanied by brief notes as to their origin, application, and spelling. This list has been prepared in the absence of the authors of the papers, who can not therefore be held solely responsible for the names as they appear in their papers and on their maps. In some cases the spelling used by the authors has not been followed, departures having been made in the interest of simplicity and uniformity as well as for the purpose of correcting supposed errors and inconsistencies.

The list is not exhaustive, i. e., does not contain every name on every map in the Twenty-first Annual Report relating to Alaska. It does aim, however, to include all geographic names used in the text of those Alaskan papers.

ALASKAN GEOGRAPHIC NAMES APPEARING IN PART II OF THE TWENTY-FIRST ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

ABERCROMBIE; mountain near latitude $61\frac{1}{2}^{\circ}$ and longitude 142° . Named by the United States Geological Survey in 1899 after Capt. William R. Abercrombie, U. S. A.

ABERCROMBIE; see Klutena.

ADAMS; creek tributary to Middle Fork of the Koyukuk River from the north near longitude 150° . Prospector's name, now first published.

ADMIRALTY; see Yakutat.

AGULOGAK; see Naknek.

AGUSTA; see Augusta.

AIRS; hill near international boundary, in latitude $62\frac{1}{2}^{\circ}$. Named in 1898 by Peters and Brooks, of the United States Geological Survey, after A. R. Airs, a member of their party.

AISHIHIK; lake and a village on its shore, in the southwest part of Yukon district, Canada. Apparently Ta-ku-ten-ny-ee of Davidson. Glave in 1892 reported the name as I-she-ik. It has also been written Ishih and I-shi-ih and, erroneously, Ashink. The above form, Aishihik, has been adopted by the Canadian Board on Geographic Names.

AKHA; see Chilkoot.

ALASHUK; river tributary to the Koyukuk from the north opposite Waite Island, near longitude $154\frac{1}{2}^{\circ}$. Has been written Allashook and Alloshook. Apparently it is identical with Batzakakat River of Allen in 1885.

ALEUTIAN; mountains on Alaska Peninsula northeast of Becharof Lake. Named by the United States Geological Survey in 1898.

ALLEN; mountain near head of Tanana River. Named by the United States Geological Survey in 1898 after Maj. Henry T. Allen, U. S. A.

ALLEN; river tributary to the Koyukuk from the north near the Arctic Circle. Named Allenkakak by Allen in 1885, the termination kakat meaning river. Has been written Allenkakak, Allankakat, and Allatna. See Kakat.

ALSEK; river in St. Elias region, debouching between Lituya and Yakutat bays. Called Riviere de Behring by La Perouse in 1786, Alsekh by Tebienkof in 1849, and Harrison by the Coast and Geodetic Survey in 1890. Various written Alseck, Alsekh, Altsekh, Alzech, etc. The above form, Alsek, has been adopted by the United States and Canadian Boards on Geographic Names. The form Alseck, in the first report of the Canadian Board on Geographic Names, is a typographical error.

AMANKA; lake near north shore of Bristol Bay, drained by the Igushik River. Native name, according to Spurr and Post of the United States Geological Survey. Petrof reported its name in 1880 as Pogakhluk.

AMBLER; river tributary to the Kowak from the north near longitude 158° . Named in 1890 after Dr. James M. Ambler, surgeon of the De Long arctic expedition.

AMERICAN; creek in the Eagle mining district. Named by prospectors in 1898.

ARCHER; see Tonsina.

ARCTIC; city on Koyukuk River near Arctic Circle. Named by prospectors in 1899.

ARKELL; see Kusawa.

ASCHEESHNA; see Fickett.

ATNA; see Copper.

- AUGUSTA; mountain in St. Elias region, named by Prof. Israel C. Russell, after his wife. Has been published erroneously as Agusta.
- BABY; creek tributary to Chandlar River from the west near longitude $148\frac{1}{2}^{\circ}$. Named by prospectors in 1899.
- BAIE DE MONTI; see Yakutat.
- BAKER; creek tributary to the Tanana from the north near longitude 151° . Named by Allen in 1885.
- BAKER; creek tributary to Middle Fork of the Koyukuk from the north near longitude 150° . Named by prospectors in 1899. Also called Nelson Creek.
- BAKER; mountain on west bank of White River near latitude 63° . Named in 1898 by Peters and Brooks, of the United States Geological Survey, after H. B. Baker, a member of their party.
- BATES; rapids in the middle part of the Tanana River. Named by Allen in 1885.
- BATZA; village, mountains, and river tributary to the Koyukuk River from the north near longitude 154° . Native name, reported by Allen in 1885 as Batzakakat. See Kakat and also Alashuk.
- BATZULNETAS; post on north bank of the Copper River, in latitude $62^{\circ} 37'$. Apparently a native name; published by the United States Coast and Geodetic Survey in 1898. Has also been written Batzulnatos.
- BEAN; ridge on the north bank of Tanana River, opposite mouth of Toklat River. Named by the United States Geological Survey in 1899 after Mrs. Bean, wife of a fur trader at Harper Bend, who was murdered by the Indians.
- BEAR; creek tributary to South Fork of the Koyukuk from the south near latitude 67° . Named by prospectors in 1899.
- BEAVER; creek tributary to the Yukon from the south near latitude 66° . Name published by United States Coast and Geodetic Survey in 1897. This may be the stream called Nocotocargut by the Western Union Telegraph Expedition in 1867.
- BECHAROF; lake and mountains, Alaska peninsula. The lake was named at an early day by the Russians after Becharof, a master in the Russian navy, who was at Kadiak in 1788. It has been variously written Becharoff, Betchareff, Bocharof, Bochonoff, Botcharoff, Rochanoff, etc. The Eskimo name appears to be Igiagiuk, or Ugiagwik, or Ugashik, etc. It has also been known as Tugat or Ninuan-Tugat, etc. The above form, Becharof, has been adopted by the United States Board on Geographic Names.
- BEND; mountain (5,000 feet) on east bank of Chandlar River near latitude 68° . Descriptive name given by the United States Geological Survey in 1899. There is a large bend in the river near this mountain.
- BENNETT; lake and town at its head, terminus of the railroad from Skagway. Lake Bennett was named by Schwatka in 1883 after Mr. James Gordon Bennett.
- BERGMAN; post or mining camp on the Koyukuk near Arctic City. Named by miners in 1899.
- BERING BAY; see Yakutat.
- BERING RIVER; see Alek.
- BETTLES; river tributary to the Middle Fork of the Koyukuk from the east near longitude 150° . Named in 1899 after Mr. Bettles, of the firm Pickarts, Bettles & Pickarts, owners of the post Bergman.
- BIG; creek tributary to the Chandlar River from the east near longitude 149° . Named by prospectors in 1899.
- BIG BLACK; river tributary to the Porcupine from the east near longitude 145° . Named by the United States Coast and Geodetic Survey in 1890.
- BIRCH; creek tributary to the Yukon from the south a little below Fort Yukon. Named by traders of the Hudson Bay Company. Its Indian name is reported to be Tohwun-nukakat. Either this creek or the one next below it is Nocotocargut of the Western Union Telegraph expedition of 1867.

- BITZLA**; river tributary to the Koyukuk from the east near longitude 157½°. Part of a native name reported in 1885 by Allen, who has Bitzlatoilocta on his map and Bitzlatoiloeta in his text.
- BLACKBURN**; mountain east of and near the Copper River. Named in 1885 by Allen after Hon. J. C. S. Blackburn, of Kentucky.
- BLACKBURN**; river tributary to Copper River from the east a little south of latitude 62°. Named by Abercrombie in 1898.
- BOCHAROFF**; see Becharof.
- BOULDER**; creek tributary to the Klehini River, in the Porcupine gold district. Prospector's name, now first published.
- BOUNDARY**; creek tributary to the White River from the south near the international boundary. Descriptive name.
- BOVE**; see Tagish.
- BRANCH**; creek tributary to South Fork of the Koyukuk from the east near latitude 68°. Name published by United States Coast and Geodetic Survey in 1899.
- BRISTOL**; see Nushagak.
- BRONSON**; creek tributary to Middle Fork of the Koyukuk from the north near longitude 150½°. Prospector's name, now first published.
- BULSHALA**; see McKinley.
- CANTWELL**; river tributary to the Tanana from the south near longitude 149°. Named in 1885 by Allen, presumably after Lieut. John C. Cantwell, U. S. R. M., who explored the Kowak River in 1884 and 1885. According to Peters and Brooks the native name is Tutlut.
- CARIBOU**; mountain on west bank of White River near latitude 63°. Named by Abercrombie in 1898.
- CARIBOU**; see Cutler.
- CARMEL**; Moravian mission and school, established in 1886, near the mouth of the Nushagak River.
- CATHEDRAL**; bluff and rapids on the Tanana near longitude 144°. Descriptive name given by Allen in 1885.
- CHANDLAR**; lake and river tributary to the Yukon from the north near the Arctic Circle. Locally known as the Chandlár and said to be named after John Chandlar, a factor of the Hudson Bay Company. Has also been called Gens de Large. The above name, Chandlar, has been adopted by the United States Board on Geographic Names.
- CHAPMAN**; creek tributary to Middle Fork of the Koyukuk from the east near longitude 148°. Prospector's name, published by the United States Coast and Geodetic Survey in 1899.
- CHENA**; river tributary to the Tanana from the east near longitude 147½°. Native name reported by the United States Geological Survey in 1898.
- CHENTANSUETAN**; village on north bank of the Yukon near longitude 156°. Native name published by the United States Coast Survey in 1898.
- CHILKAT**; inlet, islands, lake, mountains, pass, peak, point, and river at the head of Lynn Canal. A native word, variously written Chilcat, Chilkah, Tchillkat, Tschillkat, T'silkat. The form Chilkat is in general use and has been adopted by the United States and Canadian Boards on Geographic Names.
- CHILKOOT**; inlet, lake, mountains, pass, and village near head of Lynn Canal. A native name, variously written Chilcoat, Tschilkut, etc. The inlet has been called False Chilkah or Tschillkat; the lake, Akha; the pass, Dejah and Perrier; and the village Tananei or Chilcoat. The form Chilkoot has been adopted by both the United States and Canadian Boards on Geographic Names.
- CHISTECHINA**; river tributary to the Copper River from the north near latitude 63°. Native name, reported by Allen (text pp. 65, 66) in 1885 as Chitslétchiná. On his maps it is Chistotchiná. Has also been written Chestochena, Chistochina, and Tieschemni.

- CHITINA**; river tributary to the Copper River from the east near latitude 62°. A native name, reported in 1885 by Allen, who spells it Chittyna (from chitty=copper and na=river). Hayes writes it Chittenah; Brooks, Chittena; Abercrombie, Chettyna.
- CHITSTONE**; river tributary to the Chitina. Named Chittystone by Allen in 1885 (from chitty=copper and stone=stone), i. e., Copperstone River, on account of copper discolorations on the boulders and rocks of the river's bed.
- CHUGACH**; mountains near head of Cook Inlet. A native word obtained by the early Russian traders and by them written Chugatz and Tchougatskoi. Now usually written Chugach or Chugatch.
- CIRCLE CITY**; trail and also mining camp on west bank of the Yukon near the Arctic Circle; hence the name which was given by the prospectors.
- CLARK**; lake near Iliamna Lake. Discovered and named in 1891 after John W. Clark, chief of the Nushagak trading post.
- COFFEE**; point near mouth of the Nushagak River. Trader's name, published by the U. S. Fish Commission in 1891.
- COLVILLE**; river draining to the Arctic Ocean near longitude 151°. Named by Dease and Simpson in 1837 after Andrew Colville, esq., of the Hudson Bay Company. On Dease and Simpson's map it was spelled Colville. This form thus gained currency and has been adopted by the United States Board on Geographic Names. The Eskimo name is reported to be Or-kim-ya-nook. Ray (Report, 1885, p. 55) says: "The Colville River was always spoken of as 'Neg-a-len-mi-ku,' 'the river at Negalek,' and we did not obtain the name."
- CONE**; mountain on north bank of Koyukuk River near longitude 156°. Descriptive name given by the United States Geological Survey in 1899.
- COOK**; inlet on south coast of the Alaskan mainland. First explored and mapped by Capt. James Cook in 1778. Not having in his journal applied any name to it "Lord Sandwich directed that it should be called Cook's River." Vancouver calls it Cook's Inlet, and also refers to it as Groosgincloose or Cook's Inlet. The Russians call it Kenai Bay. It has been called an arm, bay, gulf, inlet, and river, and the name Kenai has been rendered Kenaïskoi, Kenaïskaia, Kenaïskischer. According to Grewingk, quoting Zagoskin, the correct name is "Tunaïskysch" Bay.
- COOPER**; pass between the Nabesna and Tanana rivers near latitude 62°. So named by Peters in 1899.
- COPPER**; river discovered by Nagaief in 1781 and called by the Russians Miednaia (copper) and by the natives Atna. Has been usually referred to as the Atna or Copper River.
- COPPER CENTER**; mining camp or village on the Copper River. Prospector's name, first published in 1898.
- COPPER RIVER**; plateau between the Copper and Sushitna rivers, about latitude 62°. Named by Abercrombie in 1898.
- CRANBERRY MARSH**; prospector's name for the flat, marshy mouth of the valley northwest of Klutena Lake.
- CREADON**; river tributary to Klutena Lake from the east near latitude 61°. Named by the United States Geological Survey in 1899.
- CRIPPLE**; creek tributary to South Fork of the Koyukuk from the south near latitude 67°. Prospector's name, now first published.
- CROOKED**; creek tributary to Birch Creek from the west near Circle City. Descriptive name, published by the United States Coast Survey in 1895.
- CUDAHY**; post on west bank of the Yukon near Fortymile Creek. Also called Fort Cudahy. The above form, Cudahy, has been adopted by the Canadian Board on Geographic Names.
- CUTLER**; river tributary to the Noatak from the south near longitude 158°. Name published by U. S. Coast Survey in 1890. Has recently been called Caribou.

- DAGITLI**; river tributary to the Koyukuk from the north near longitude 157°. Native name, reported by Allen, in 1885, as Doggetlooscat and Doggetlooskat. Schrader writes it Doggetlikakat. See Kakat.
- DAKLI**; river tributary to the Koyukuk from the north near longitude 157°. Native name, reported by Allen in 1885. Has been written Daklikakak, Daklikakat, and Dakliakakat. See Kakat.
- DALL**; river tributary to the Yukon from the north at the Lower Ramparts. It is Notokakat or Dall of the United States Coast Survey, 1869, and Notochangut or Dall of Raymond, 1871.
- DALTON**; post, range of mountains, and trail from head of Lynn Canal to the interior. The name, as applied to the mountain range, has been adopted by the Canadian Board on Geographic Names.
- DASSAR-DEE-ASH**. See Dezadeash.
- DAVIS**; creek tributary to South fork of the Koyukuk from the south near latitude 67°. Prospector's name, published by United States Coast Survey in 1899.
- DAWSON**; peak near Teslin Lake, Yukon.
- DAWSON**; range of mountains at the confluence of the Lewes, Pelly, and Yukon rivers, Yukon.
- DAWSON**; town, Government headquarters, and post-office on Yukon River, at mouth of Klondike River, Yukon. (Not Dawson City.) The above entry for Dawson is copied from the First Annual Report of the Canadian Board on Geographic Names. Named after Dr. George M. Dawson, of the Canadian Geological Survey.
- DEASE**; creek, lake, and river of British Columbia. Named as early as 1867, and perhaps earlier, after Peter Warren Dease, of the Hudson Bay Company.
- DEITRICK**; see Dietrich.
- DELAH**; see Chilkoot.
- DELTA**; river tributary to the Tanana from the south near longitude 146°. So named by Allen in 1885 and erroneously on a late map as Delt.
- DELTA**; see Silok.
- DENNISON**; fork of Fortymile Creek. Named by Abercrombie in 1898. Has also been written Denison.
- DEZADEASH**; lake back of the St. Elias range of mountains. Native name reported by Davidson as Tots-an-tee-ash and by E. J. Glave in 1892 as Dassar-dee-ash. Various written Deza-de-ash, Dazadeash, etc. The above form, Dezadeash, has been adopted by the Canadian Board on Geographic Names.
- DIETRICH**; river tributary to Middle Fork of the Koyukuk, near its source. Published in 1899 by United States Coast Survey with the spelling Deitrick, here changed to Dietrich.
- DISCOVERY**; creek tributary to Birch Creek from the south near latitude 66°. Prospector's name, published by the Coast Survey in 1898.
- DOGGETLOOSCAT**; see Dagitli.
- DONJEK**; river tributary to the White from the south in latitude 62°. The form Donjek has been adopted by the Canadian Board on Geographic Names.
- DOUBLE POINT**; mountain on north bank of the Koyukuk near Arctic City. Descriptive name given by Allen in 1885.
- DRUM**; mountain east of Copper River near longitude 144°. Named in 1885 by Allen after Adj. Gen. Richard C. Drum, U. S. A.
- DUGAN**; river tributary to the Tanana from the south near longitude 150°. Named in 1885 by Allen after Lieut. Thomas B. Dugan, U. S. A.
- DULBI**; river tributary to the Koyukuk from the east in longitude 156½°. Native name, reported by Allen in 1885. Usually written Dulbikakat. See Kakat.

- DYEA; port of entry and post-office at head of Lynn Canal. The inlet was called Tyya by Meade in 1869, Dejah by Krause in 1882, Dayay by Schwatka in 1883, and Chilkoot or Taiya by the miners according to Dawson (Rept. Canadian Geological Survey, 1887-88, p. 174 B). The United States Board on Geographic Names has adopted the name Dyea as the name of the port of entry and post-office, and Taiya as the name of the inlet and river.
- EAGLE; mining camp on west bank of the Yukon near latitude 65°. Prospector's name is Eagle City.
- EAST; fork of the Chandlar River near longitude 147°. Prospector's name, now first published.
- EGOUSHIK; see Igushik.
- EKUK; cape and Eskimo village near mouth of the Nushagak River. Native name, given by Lütke in 1828 as Ekouk.
- ELDORADO; creek tributary to South Fork of the Koyukuk from the east near longitude 147°. Prospector's name, now first published.
- FAREWELL; see Pyramid.
- FAULT; mountain on headwaters of the Koyukuk River near latitude 68°. Named by the United States Geological Survey in 1899.
- FICKETT; river tributary to the Koyukuk from the north near longitude 150°. Named in 1885 by Allen after Private Fred W. Fickett, U. S. A., a member of his party. Allen calls it the Ascheeshna or Fickett. Has also on late maps been called Oschesna and Ochesna.
- FISH; creek tributary to Chandlar River from the east near latitude 68°. Named by the United States Geological Survey in 1899.
- FISH; creek tributary to South Fork of the Koyukuk from the south near longitude 151°. Name published by Coast Survey in 1899.
- FLAG; hill on east bank of Tanana River near longitude 147°. Descriptive name given by the United States Geological Survey in 1898.
- FLAT; creek tributary to Chandlar River from the north near longitude 148°. Named by prospectors in 1899.
- FLORENCE; bar on Koyukuk River near longitude 154°. Named by prospectors in 1899.
- FOHLIN; creek. Name in manuscript. Not identified.
- FORT ADAMS; see St. James.
- FORT ALEXANDER; see Nushagak.
- FORT COSMOS; post on Kowak River near longitude 157°. Presumably named by the traders.
- FORT CUDAHY; see Cudahy.
- FORT HAMLIN; post on the south bank of the Yukon near longitude 149°. Presumably a trader's name. First published by the Coast Survey in 1897.
- FORT SELKIRK; Canadian military headquarters at the mouth of Lewes River. The site of the old fort of the Hudson Bay Company is on the opposite bank of the river. This name has been adopted by the Canadian Board on Geographic Names.
- FORTYMILE; town and trail; also creek tributary to the Yukon from the west near latitude 64½°. Prospector's name, given, presumably, in 1886, when gold was first discovered here. The creek is about 40 miles below old Fort Reliance. The above form, Fortymile, has been adopted by the Canadian Board on Geographic Names.
- FRANKLIN; creek tributary to South Fork of Fortymile Creek. Prospector's name, reported by United States Geological Survey in 1898.
- FREDERICK; lake east of and near Dezadeash Lake in longitude 137°. Name published by the Canadian Board on Geographic Names in 1899.

GENS DE LARGE; see Chandler.

GENS DES BUTTES; see Tanana.

GEROE; creek tributary to the Chandler River from the south near latitude 68°. Presumably a miner's name; reported by the United States Geological Survey in 1899.

GIBSON; creek tributary to Dietrich River from the west near latitude 68°. Presumably a miner's name; reported by the United States Geological Survey in 1899.

GISASA; river tributary to the Koyukuk River from the west near latitude 65°. Native name, reported by Allen in 1885. In his text, page 106, it is Gissassakakat; on his map 4 it is Gissakakat. See Kakat.

GLACIER; bay penetrating the Alaskan mainland in the Fairweather region. Explored and named by United States naval officers in 1880. Descriptive name.

GLAVE; river tributary to Chilkat River from the west. Named in 1899 by the United States Geological Survey after Mr. E. J. Glave, who explored in this region in 1891.

GOLD; creek tributary to Middle Fork of the Koyukuk from the east near longitude 150°. Prospector's name, reported by United States Geological Survey in 1899.

GRANITE; creek tributary to Chandler River from the west near latitude 67°. Prospector's name, reported by United States Geological Survey in 1899.

GRANITE; creek tributary to South Fork of the Koyukuk from the east near longitude 150°. Prospector's name, reported by United States Geological Survey in 1899.

GRAVE; creek tributary to Middle Fork of Chandler River near longitude 148°. Prospector's name, reported by United States Geological Survey in 1899.

HAINES; mission, post-office, and village at head of Lynn Canal. The mission was established by the Presbyterians in 1880.

HARPER; "About 20 miles below Toclut River is the log house once used by Mr. Harper as a trading station; also the scene of Mrs. Bean's murder while her husband was a fur trader there." (Allen, page 86.) This post is in a bend in the river and is sometimes referred to as Harpers Bend.

HARRIET; creek tributary to the Koyukuk from the south near longitude 151°. Prospector's name, reported by the United States Geological Survey in 1899.

HARRISBURG; see JUNIOR.

HARRISON; see Alsek.

HAYES; glacier and river flowing from it to the Skwentna northwest of Cook Inlet. Named by the United States Geological Survey in 1898 after Dr. C. Willard Hayes.

HAYES; mountain near longitude 147°, latitude 63½°. Named by the United States Geological Survey in 1898 after Dr. C. Willard Hayes. Erroneously "Hays" on a recent chart.

HESS; creek tributary to the Yukon from the east near Rampart City. Apparently identical with Whymper River of the Coast Survey in 1869.

HOGATZA; river tributary to the Koyukuk from the north near longitude 156°. Native name reported by Allen in 1885. Usually written Hogatzakakat. See Kakat. This may be the same river as the one called Hokachatna.

HOKOTENA; river tributary to the Koyukuk from the north near longitude 149°. Native name, published by the Coast Survey in 1899.

HOLOÖATNA; see Kowak.

HOOTALINQUA; see Teslin.

HOOTHY-EYE; see Hutshi.

HORACE; mountain on headwaters of Koyukuk River near longitude 149°. Prospector's name, reported by the United States Geological Survey in 1899.

HOT SPRINGS; 20 miles northwest of Katnai.

HUBBARD; mountain near Yakutat Bay; named in 1891 by the National Geographic Society after its president, Gardiner G. Hubbard.

HUDSON BAY; creek tributary to South Fork of the Koyukuk from the south near latitude 67°. Prospector's name, reported by the United States Geological Survey in 1899.

HUNGARIAN; creek tributary to South Fork of the Koyukuk near longitude 150°. Prospector's name, reported by the United States Geological Survey in 1899.

HUSLIA; river tributary to the Koyukuk from the west near longitude 156½°. Native name, reported by Allen in 1885 as Hussliakatna on his maps 1 and 4, and Husliakakat in his text, page 105. See Kakat.

HUTSHI; chain of lakes draining northward into the Lewes River in longitude 137°. Native name, apparently first published by Glave in the Century, September and October 1892, where it is spelled Hootchy-Eye. It has been variously written Hootch Eye, Hootch-i, Hutchi, Hotchi, Huchai, etc. The Canadian Board on Geographic Names has adopted the above form, Hutshi.

IGAGIK; see Ugagik.

IGIAGIUK; see Becharof.

IGUSHIK; river draining from Amanka Lake to Nushagak River. Eskimo name, reported by Petrof in 1880 as Igushek, by the United States Fish Commission in 1890 as Egashak, by the United States Coast Survey in 1897 as Egashik, and by Spurr of the United States Geological Survey in 1898 as Egoushik.

INLAND; see Noatak.

ISHIUK; see Aishihik.

JACK WADE; see Wade.

JIM; river draining into the South Fork of the Koyukuk from the south near longitude 151°. Prospector's name, published by U. S. Coast Survey in 1899.

JIMTOWN; mining camp at the mouth of Jim River near longitude 151°. Prospector's name, reported by the United States Geological Survey in 1899.

JOHNSTON; hill near mouth of Naknek River, Bristol Bay. Named by the United States Fish Commission in 1890.

JUKCHANA; see Yukon.

JUNEAU; city, harbor, and island, southeastern Alaska. "Two prospectors, Harris and Juneau, found mineral here in 1880, and soon afterwards a camp was located." This camp, it is said, was named Harrisburg and the district Juneau. United States naval officers reconnoitered the harbor about this time, and called the camp Rockwell, after Commander Charles H. Rockwell, U. S. N. Owing to the resulting confusion in names, the residents held a town meeting and adopted the name Juneau.

KAIYUT; mountains south of the Yukon River, in longitude 158°; also river, near same, tributary to the Yukon from the south. Native name, reported presumably by Dall and published in 1869.

KAKAT; This is an Indian word used in northwestern Alaska, meaning river, and is appended to the name. Thus we have:

Allenkakak River=Allen (river) River.

Batzakakat River=Batza (river) River.

Daklikakat River=Dakli (river) River.

Dulbikakat River=Dulbi (river) River.

Gisasakakat River=Gisasa (river) River.

Hogatzakakat River=Hogatz (river) River.

Husliakakat River=Huslia (river) River.

Tozikakat River=Tozi (river) River, etc.

In such cases it has been thought best to drop the generic termination *kakat* and write Allen, Batza, Dakli, etc. This word *kakat* was written in 1871 by Captain Raymond, U. S. A., on his maps of the Yukon, "kargut" and "char-gut," as, Atutsakulakuschchargut, Tosekargut, etc.

- KANUTENA**; village; also river tributary to the Koyukuk from the south near Arctic City. Native name, reported by Allen in 1885 and by him written Konoótená. This is apparently Old Man River of the prospectors.
- KASKAWULSH**; river tributary to the Alsek River. Native name, published in 1898 and probably earlier. Has been variously written Kaskarwulch, Kaskarwulch, etc. The above form, Kaskawulsh, has been adopted by the Canadian Board on Geographic Names.
- KATEEL**; river tributary to the Koyukuk from the west in latitude $65\frac{1}{2}^{\circ}$. Native name, reported by Allen in 1885. Usually written Kateelkakat; see Kakat.
- KATMAI**; bay, creek, and village on north shore of Shelikof Strait. Native name, reported by the Russians. Lütke in 1828 calls it Katnaiskoi.
- KATRINA**; river tributary to the White from the west in latitude 63° . This name has been adopted by the Canadian Board on Geographic Names. It is apparently an error for the native word Katsiná, published by the United States Coast Survey in 1890.
- KETCHUMSTUK**; range of hills south of the Tanana, in longitude 145° . Often called Razorback Divide by prospectors. On Coast Survey Chart T, editions of 1895 and 1896, it is called Razor Back Divide, and on later editions and maps Ketchumstock Hills.
- KENAI BAY**; see Cook Inlet.
- KENNICOTT**; glacier and creek flowing from it near latitude $61\frac{1}{2}^{\circ}$. Named in 1899 by the United States Geological Survey, presumably after Robert Kennicott, a pioneer on the Yukon River, who died at Nulato, May 13, 1866.
- KHILTAT**; river tributary to the Tanana from the north near longitude $144\frac{1}{2}^{\circ}$. Named by Allen in 1885 after an Indian chief, Kheeltat.
- KIMBALL**; mountain south of the Tanana River near longitude 145° . Named by Allen in 1885.
- KINIAAK**; see Nakhek.
- KLANAKAKAT**; see Minook.
- KLATSUTA**; river tributary to the Yukon from the south below the Tanana. Native name, reported by Allen in 1885 as Klatsutakakat; see Kakat.
- KLEHINI**; river tributary to the Chilkat from the west in latitude $59^{\circ} 24'$. Native name, reported by United States naval officers in 1880 as Kluheený. Krause in 1882 spelled it Tlehini. The above form, Klehini, has been adopted by the Canadian Board on Geographic Names.
- KLETSAN**; creek flowing northward to the White River near longitude 141° . Native name, reported by Hayes in 1891 as Klet-san-dek, or Copper Creek, the termination *dek* meaning creek.
- KLONDIKE**; gold district; also river tributary to the Yukon from the east near latitude 64° . This river was named Deer River by the Western Union Telegraph Expedition of 1867, and so appeared on various maps. Later it was called Raindeer and afterwards Reindeer. Ogilvie, writing September 6, 1896, from Cudahy, says: "The river known here as the Klondike," and in a footnote says: "The correct name is Thron Duick." It has also been called Clondyke and Chandik or Deer.
- KLOTASSIN**; river tributary to the White from the east near latitude $62\frac{1}{2}^{\circ}$. Native name, reported by Hayes in 1891. The above form, Klotassin, has been adopted by the Canadian Board on Geographic Names.
- KLUANE**; lake and river flowing therefrom to the Donjek River near latitude $61\frac{1}{2}^{\circ}$. Native name, reported by Hayes in 1891 as Kluantu River, the termination *tu* meaning river. The name has also been written Kluahne. The above form, Kluane, as applied to both lake and river, has been adopted by the Canadian Board on Geographic Names.
- KLUANTU**; see Kluane.
- KLUK-TASSI**; see Lebarge.

- KLUKWAN**; village near the mouth of Chilkat River. Native name, first reported by naval officers in 1880 as Chilkat or Klukquan. Krause in 1882 calls it Kloquán. The above form, Klukwan, has been adopted by the Canadian Board on Geographic Names.
- KLUTENA**; glacier, lake, and river emptying into Copper River. Native name, adopted by several hundred prospectors who camped at the lake in the season of 1898; has also been called Abercrombie.
- KLUTLAN**; glacier and river draining from it northward to the White River in longitude 141° . Native name, reported by Brooks in 1899.
- KOGIUNG**; Eskimo village at mouth of Kvichak River, Bristol Bay. Native name, reported by Petrof in 1880, who spelled it Koggiung.
- KOIDEEN**; river tributary to the White River from the south near longitude $140\frac{1}{2}^{\circ}$. Native name, reported by Hayes in 1891.
- KOTSINA**; river near Mount Wrangell, tributary to Copper River from the east in latitude $62\frac{1}{2}^{\circ}$. Native name, reported by the U. S. Geological Survey in 1899.
- KOWAK**; river tributary to Hotham Inlet, Kotzebue Sound. An Eskimo word, long in use and variously spelled Kooak, Kowuk. According to Spurr it is Kubuk or Kuvuk, meaning great river. According to Allen it is Holoóatna or Kowak River. It has also been called Putnam or Kowak River.
- KOYUKUK**; river tributary to the Yukon from the north a little above Nulato. Also a mountain near the mouth of the river. A native name, reported by the Western Union Telegraph Expedition in 1867 as Coyukuk. On Coast Survey maps it has been called Kouiak, Koyoukuk, and Koyukuk. The above form, Koyukuk, has been adopted by the United States Board on Geographic Names.
- KUSAWA**; lake northwest of Chilkat Pass draining to Lake Lebarge. Native name, written Kussoó by Krause in 1882, Küssüa by the Coast Survey in 1883, Kusawah by the Canadian Geological Survey in 1898. Has also been called Arkell. The above form, Kusawa, has been adopted by the Canadian Board on Geographic Names.
- KUSKOKWIM**; bay and river, western Alaska. A native name, reported by Lütke in 1828 as Kouskokvim. Variously written Kuskokvim, Kouskoquim, etc. The above form, Kuskokwim, has been adopted by the United States Board on Geographic Names.
- KUSKULANA**; creek tributary to the Chitina from the east near latitude $61\frac{1}{2}^{\circ}$. A native name, reported by the United States Geological Survey in 1899.
- KVICHAK**; village, and river draining from Iliamna Lake to Bristol Bay. Native name, reported by the early Russians. Lütke, writing in 1828, says "Kvitchak called by Cook Bristol."
- KWIKPAK**; see Yukon.
- LABERGE**; see Lebarge.
- LABOUCHERE**; see Pyramid.
- LACHINA**; creek tributary to Chitina River from the north in longitude $143\frac{1}{2}^{\circ}$. Native name, reported by the United States Geological Survey in 1899.
- LADUE**; creek tributary to the White River from the west near longitude 140° . Presumably named after a prospector, La Due, who wintered on the Yukon in 1884-85.
- LAKE**; creek tributary to Chandlar River from the east near longitude $148\frac{1}{2}^{\circ}$. Presumably a descriptive name, now first published.
- LEBARGE**; lake and river in the Yukon district, Canada. Named in 1868 by the Western Union Telegraph Expedition, after Michael Lebarge. According to Schwatka the native name is Kluk-tássi. The above form, Lebarge, has been adopted by the United States Board on Geographic Names, that form being the one used by Lebarge himself. The Canadian Board on Geographic Names has adopted the form Laberge.

- LEWES**; river tributary to the Upper Yukon. The present usage appears to regard the Yukon as beginning at the junction of the Lewes and Pelly rivers at Fort Selkirk. Often written Lewis. The above form, Lewes, has been adopted by the Canadian Board on Geographic Names.
- LIARD**; river tributary to the Mackenzie from the west. Has also been called Mountain River. The above name, Liard, has been adopted by the Canadian Board on Geographic Names.
- LIMESTONE**; creek tributary to Bettles River from the north near longitude 149½°. Descriptive name, now first published.
- LOGAN**; mountain (19,539 feet) in the St. Elias region. Named by Prof. Israel C. Russell, in 1890, in honor of Sir William E. Logan, "founder and long director of the Geological Survey of Canada." The name has been adopted by the Canadian Board on Geographic Names.
- LOOKOUT**; mountain about 800 to 1,000 feet above the river on west bank of Koyukuk River near latitude 67°. Named by Allen, who ascended it in August, 1885.
- LORENTZ**; river tributary to the Tanana from the south near longitude 150½°. Named by Allen in 1885 after Mr. Lorentz, of the Alaska Commercial Company, chief trader for the Yukon country. On some maps it is Lorenz.
- LOWE**; point and river on north shore of Port Valdes, Prince William Sound. Named by Abercrombie in 1898.
- LYNN**; canal, first explored and named by Vancouver in 1794.
- MACKENZIE**; river, named after its first explorer, Alexander Mackenzie.
- MCKINLEY**; creek in Porcupine gold district. Prospector's name, now first published.
- MCKINLEY**; mountain (20,460 feet) near headwaters of Kuskokwim River. Name published by the United States Coast Survey in 1897. Also called Bulshaia, a corruption of the Russian word for *big*.
- MACMILLAN**; mountains (3,500 feet), and river tributary to Pelly River from the east near latitude 63°. This form has been adopted by the Canadian Board on Geographic Names.
- MAHUTZU**; creek or river tributary to the Tanana from the south near longitude 146½°. Native name, reported by United States Geological Survey in 1898.
- MARION**; creek tributary to Middle Fork of the Koyukuk from the east near longitude 150°. Prospector's name, reported by the United States Geological Survey in 1899.
- MARSH**; lake northeast of Chilkoot Pass, on headwaters of Lewes River. Named in 1883 by Schwatka, after Prof. O. C. Marsh, of Yale College. This name has been adopted by the Canadian Board on Geographic Names.
- MASON**; riffows in Tanana River near longitude 146°. Named in 1885 by Allen in honor of Prof. O. T. Mason of the Smithsonian Institution.
- MAUD**; lake draining to Kusawa Lake near latitude 60°. Name published by Coast Survey in 1895.
- MELOZI**; river tributary to the Yukon from the north near longitude 155½°. Native name, reported by the Western Union Telegraph Expedition of 1867 as Melozecargut and usually written Melozikakat. See Kakat.
- MENA-KAK-A-SHAH**; see Walker.
- MENTANONTLE**; lake and river near longitude 152°. Native name, reported by Allen in 1885. On his map it is Mentantlekakat, and in his text, page 97, etc., it is Mentanóntlekákat. See Kakat.
- MENTASTA**; lake, mountain range, pass, and trail between Copper and Tanana rivers. Native name reported by Allen in 1885.
- MIDDLE**; fork of Chandlar River. Descriptive name.
- MIDDLE**; fork of Koyukuk River. Descriptive name.
- MILLARD**; trail about 90 miles long from Copper Center to Mentasta Pass, along the western slopes of Mounts Drum and Sanford. Prospector's name.

- MINOOK**; creek tributary to the Yukon from the east near longitude 150°. Apparently identical with Klanarchagut (? Klana-kakat) River of Coast Survey chart 900, published in 1890. Is sometimes spelled Mynook. Named, presumably, after Mr. Minook, interpreter at Fort Reliance.
- MIRROK**; creek tributary to the Tanana from the east near latitude 62½°. Descriptive name, given by the United States Geological Survey in 1898.
- MOOSEHORN**; mountain near international boundary and latitude 63°. Named by United States Geological Survey in 1898.
- MOSQUITO**; fork of South Fork of the Koyukuk near longitude 150°. Descriptive name, given by prospectors.
- MUIR**; large glacier at head of Glacier Bay. Named, in about 1880, after John Muir.
- MYNOOK**; see Minook.
- MYRTLE**; creek tributary to Middle Fork of the Koyukuk, from the east, near longitude 150°. Prospector's name, reported by the United States Geological Survey in 1899.
- NABESNA**; river, one of the principal tributaries of the Upper Tanana. According to Allen, page 136, "The natives of the Upper Tanana call that river Nabesna."
- NAKNEK**; lake and river draining from it and village at mouth of river. Apparently a corruption of an Eskimo name, first reported by early Russian surveyors. The earliest Russians reported the name of the river to be Naknek, and of the lake, Agulogak. Lütke, in 1828, calls both lake and river Naknek. Tebienkof, in 1849, also gives Naknek, with Naugvik as an alternative form, this being taken from old Russian charts. A Russian post at or near the village was named Fort Suworof, and variously written Souworoff, Suvaroff, etc. This seems for a time to have superseded the native name of the village. Petrof, in 1880, named the lake Walker, after Gen. F. A. Walker, Superintendent of the Census, and reported the name of the village to be Kinghiak, on late maps Kiniaak. Out of all this confusion the above form *Naknek* has been selected and adopted by the United States Board on Geographic Names.
- NATAZHAT**; mountain range north of Mount St. Elias. Native name, reported by Hayes in 1891 as Nat-azh-at.
- NATSINA**; see White.
- NAUGVIK**; see Naknek.
- NEEDLES**; mountain near latitude 62° and between the one hundred and forty-first and one hundred and forty-second meridians. Descriptive name given by the United States Geological Survey in 1898.
- NELSON**; see Baker.
- NEMETH**; creek tributary to South Fork of the Koyukuk from the east near longitude 148°. Presumably a prospector's name, published by the U. S. Coast Survey in 1899.
- NEWBERRY**; see Teslin.
- NIGA To**; see Yukon.
- NIKOLAI**; house on Nizena River, south bank, near mouth of the Chitistone. Name of an Indian chief, reported by Hayes in 1891, who says "Nicolai, or Scolai, as the Yukon Indians call him."
- NILKOKA**; river tributary to the Tanana from the north near latitude 65°. Native name, reported by the United States Geological Survey in 1898.
- NISLING**; river tributary to the White River from the east near longitude 140°. Native name, reported by Hayes in 1891.
- NIZINA**; glacier and river tributary to the Chitina. Native name, reported in 1891 by Hayes, who spells it Nizzenah.
- NOATAK**; river in northwest Alaska, tributary to Hotham Inlet. On early maps this is called Inland River and sometimes Inland, or Nunatok. The prevailing modern usage is Noatak, as above given.
- NOCOTOCARGUT**; see Bean.

NOHTALOHTON; see Notaloten.

NORDENSKIÖLD; river tributary to Lewes River from the south near longitude 136°.

Named by Schwatka in 1883 after Baron A. N. E. von Nordenskiöld, the celebrated Swedish Arctic explorer.

NORTH; creek tributary to South Fork of the Koyukuk from the east near longitude 147°. Name published by U. S. Coast Survey in 1899.

NORTH; fork of Birch Creek. Name published by the Coast Survey in 1899.

NORTH; fork of Koyukuk. Prospector's name, now first published.

NORUTAK; lake near Arctic circle, drained by the Kowak. Native name, reported by Cantwell in 1885 as Nor-u-tak. Schrader, in 1899, calls it Nowgettoark.

NOTALOTEN; village (of 15 people) on north bank of the Yukon near longitude 157°. A native name, reported in the Tenth Census (1880) as Natulaten, in the Eleventh Census (1890) as Notaloten, and on U. S. Coast Survey chart 3093, edition of 1898, as Nohtalohton.

NOTOKAKAT; see Dall.

NOWGETTOARK; see Norutak.

NOWI; village, and river tributary to the Yukon from the south near longitude 154½°.

Native name, first reported by the Western Union Telegraph expedition in 1867 as Newicargut, the termination *cargut*, now written *kakat*, meaning river. (See Kakat.) Petrof, in 1880, wrote the name Noyakakat, now usually written Nowikakat.

NUDRE-WOK; see Selby.

NULATO; post or village on the Yukon River, north bank, about 400 miles above the mouth. Founded by the Russian Malakof, who, in 1838, built a blockhouse here. Shortly after, in his absence, this was burned by the Indians. It was rebuilt by Vasili Derzhabin (? Derabin) in 1842.

NUNATOK; see Noatak.

NUSHAGAK; lake between Kuskokwim River and Bristol Bay. On late maps this is called Tikchik, and the river draining from it to the Nushagak River is called Tikchik River.

NUSHAGAK; river tributary to the head of Bristol Bay. Native name, reported by the early Russian explorers as Nushegak and Nushagak. Lütke (1828) writes it Nouchagak. Apparently the same river which Cook, in 1778, named Bristol. The form Nushagak has been adopted by the United States Board on Geographic Names.

NUSHAGAK; trading post at mouth of Nushagak River. The Russians established a trading post at the mouth of the Nushagak in 1818 or 1819 and called it Alexandrovsk, perhaps after Alexander Baranof, under whose orders the post was established. Various called since then Redoubt or Fort and spelled Alexander, Alexandrovsk, Alexandrovski, etc., and erroneously Alexandra. Now generally known as Nushagak.

NUTUVUKTI; lake near Arctic circle, drained by the Kowak. Apparently a native name, reported by Schrader in 1898 as Nootowucktoy.

NUTZOTIN; range of mountains near headwaters of Tanana River. Named by the United States Geological Survey in 1898 after a tribe of Indians in the region.

O'BRIEN; creek tributary to Fortymile creek. Miner's name, published by the Coast Survey in 1898.

OBSERVATORY; see Pyramid.

OCONNOR; glacier and river northeast of Mount Hubbard. Named by the United States Geological Survey in 1899.

OLD MAN; see Kanutena.

OR-KIM-YA-NOOK; see Colville.

OSCHESNA; see Fickett.

- PAH**; rapids in the Kowak River near longitude 156°. Near these rapids debouches a river whose name, according to Cantwell, 1885, is Shok-ah-pok-shegiak river. The name of the rapids, Pah, transformed to Par, has been applied to this river.
- PASCO**; creek tributary to Middle Fork of the Koyukuk from the south near latitude 67°. Prospector's name, now first published.
- PAWIK**; an Eskimo village on the east side of Bristol Bay. Also written Pawkik and Pawig.
- PEAVEY**; post-office and mining camp on the north bank of the Koyukuk near longitude 152°. It is also called Peavy and Peavy Trading Post.
- PELLEY**; mountains, lake, and river, Yukon, Canada. Named after a former governor of the Hudson Bay Company.
- PERRIER**; see Chilkoot.
- PESTCHANI**; see Pyramid.
- PHOEBE**; creek tributary to Bettles River from the east near longitude 149°. Prospector's name, now first published.
- PICKARTS**; creek tributary to the Koyukuk from the north near Arctic City. Named in 1899 after Pickarts, of the firm of Pickarts, Bettles & Pickarts, owners of the trading post Bergman.
- PLEASANT CAMP**; place on the Dalton trail, in Pocupine gold district.
- PLEVEZNIE**; see Tazlina.
- POGAKHLUK**; see Amanka.
- PORCUPINE**; city, creek, and gold district near Chilkat River. Prospector's name, reported by the United States Geological Survey in 1899.
- PORCUPINE**; creek tributary to Middle Fork of the Koyukuk from the north near longitude 150½°. Prospector's name, now first published.
- PORCUPINE**; creek tributary to the South Fork of the Koyukuk River from the north near latitude 68°. Published by the United States Coast and Geodetic Survey in 1899. Perhaps this creek is identical with the previous one.
- PORCUPINE**; river in northeastern Alaska tributary to the Yukon. Old name, probably given by factors of the Hudson Bay Company.
- PREACHER**; creek tributary to Birch Creek from the south near latitude 66°. Name published by the United States Coast and Geodetic Survey in 1895.
- PUTNAM**; see Kowak.
- PYRAMID**; harbor, island, point, etc., at head of Lynn Canal; so named by Meade in 1869. The name is descriptive of the island. The harbor was called Labouchere Bay from the fact that the Hudson Bay Company steamer of that name often anchored there. The island was called Pestchani (sandy) by the Russians. It has also been called Farewell, Stony, and Observatory, while its Indian name is Shla-hatch, or, according to Krause, Chlachátsch.
- QUARTZ**; creek tributary to Chandlar River from the west near latitude 68°. Presumably a descriptive name, now first published.
- RAY**; river tributary to the Yukon from the west near longitude 150°. So named by Allen in 1885 after Capt. P. H. Ray, U. S. A.
- RAZORBACK**; see Kechumstuk.
- REDSTONE**; river tributary to Ambler River near longitude 158°. Descriptive name, reported by Schrader in 1899.
- REGAL**; mountain in longitude 143°, ESE. from Mount Wrangell. Named by the United States Geological Survey in 1899.
- ROBERT**; creek tributary to Bettles River from the east near longitude 149°. Prospector's name, now first published.
- ROBERTSON**; river tributary to the Tanana from the west near longitude 145°. Named in 1885 by Allen in honor of Sergt. Cady Robertson, U. S. A., a member of his party.

ROCKWELL; see Juneau.

ROMANZOF; mountain near latitude 67°. Named by Franklin in 1826 after the late Baron Romanzof, chancellor of the Russian Empire. The mountains so named are on the north coast of Alaska. Schrader applies the name to mountains considerably farther south.

ROOT; glacier near Kennicott Glacier, in longitude 143°. Named by the United States Geological Survey in 1899.

ROSE; creek tributary to the Middle Fork of the Koyukuk from the east near longitude 150°. Prospector's name, now first published.

ROUNDABOUT; mountain on north bank of Koyukuk River near longitude 156°. Apparently a descriptive name, now first published.

RUSSELL; glacier near Skolai Pass near longitude 142°. Named by the United States Geological Survey in 1899 after Prof. I. C. Russell, of Ann Arbor, Mich.

ST. ELIAS; mountain peak (18,024 feet) and range, discovered and named by Bering July 16, 1741 (o. s.). According to Topham its Indian name is Yahse-tah-shah.

ST. JAMES; mission on north bank of the Yukon near the mouth of Tozi River. An Episcopalian mission was established here in 1891 by Rev. J. L. Prevost. The place is called Fort Adams.

ST. MICHAEL; canal, bay, island, mountain (472 feet), and town, Norton Sound. A stockaded post was established here by the Russians in 1833 and, according to Zagoskin, named after Capt. Michael Dmitrievich Tebienkof, afterwards governor of the Russian-American colony. It was called Redoubt St. Michael or Michaelovski. The above form, St. Michael, has been adopted by the United States Board on Geographic Names.

SAGHADELLATAN; see Zakatlatan.

SAGAHAKAT; see Sozhekla.

SAKATALODEN; see Zakatlatan.

SALCHAKET; river tributary to the Tanana River from the east near longitude 147°. Native name, reported by the United States Geological Survey in 1898 and spelled Salchacket and Salehaket.

SALMON; river tributary to the Chilkat from the west. Name reported by Brooks, of the United States Geological Survey, in 1899.

SALMON; see Shoenjek.

SANFORD; mountain east of and near Copper River, in longitude 144°. Also river tributary to Copper River. Named by Allen in 1885 in honor of the Sanford family, his "great-grandfather being Reuben Sanford."

SAVOŠOSKI; an Eskimo village at the east end of Naknek Lake. Name obtained by the United States Geological Survey from Rev. A. Petelin in 1898.

SCOLOI; see Skolai.

SCOTTIE; creek near international boundary, between latitudes 62° and 63°. Named by Peters and Brooks in 1898 after a member of their party.

SEAFORTH; mining camp on South Fork of Koyukuk River near longitude 151°. Prospector's name, reported by United States Geological Survey in 1899.

SEAT; an isolated rock near Katmai. Name obtained by the United States Geological Survey in 1898 from Rev. A. Petelin.

SEATTLE; mountain in St. Elias region. Named by the United States Geological Survey in 1899.

SEKULMUN; lake in latitude 61½°, longitude 137½°. Apparently a native name, which has also been spelled Sekulman. The above form, Sekulmun, has been adopted by the Canadian Board on Geographic Names.

SELAWIK; lake and river tributary to Kotzebue Sound. An Eskimo name, written Salawik and Selawik. The Point Barrow natives, according to John Murdoch, pronounce it Sslawik. The above form, Selawik, has been adopted by the United States Board on Geographic Names.

- SELBY**; lake near Arctic Circle, drained by the Kowak River. Name reported by Schrader, of the United States Geological Survey, in 1899. This appears to be Nudre-wok Lake of Cantwell in 1885.
- SEVENTYMILE**; creek tributary to the Yukon from the west, near latitude 65°. Prospector's name. The creek is about 70 miles below old Fort Reliance.
- SHAK-AH-POK-SHEGIAK**; see Pah.
- SHEENJEK**; river tributary to the Porcupine from the north near longitude 144½°. Late Coast Survey charts call it Salmon River, and earlier ones give Sheenjek or Salmon. Name apparently first published in 1895.
- SHEEP**; creek tributary to Dietrich River from the west near latitude 68°. Prospector's name, reported by Schrader, of the United States Geological Survey, in 1899.
- SHEEP**; creek tributary to Robert Creek near headwaters of the Koyukuk. Prospector's name, reported by the United States Geological Survey in 1899.
- SHEVLIN**; creek tributary to the Yukon from the south near longitude 151°. Name now first published.
- SHORTY**; creek tributary to the headwaters of the Alsek. Name now first published.
- SILOK**; creek tributary to the Tanana from the south near longitude 148°. This stream was called Delta Creek by Allen in 1885. To avoid confusion with Allen's Delta River and because the exact locality of his Delta Creek is not clear, this change has been introduced by the Geological Survey. Apparently a native name, which has also been spelled Silokh.
- SKAGWAY**; river and town at the head of Taiya Inlet. So spelled by both the Canadian and United States Boards on Geographic Names.
- SKOLAI**; pass, creek, and mountains between the White and Copper rivers. Spelled variously Scolai, Scoloi. Scolai is the name by which the Copper River Chief Nicolai or Scolai is known amongst all the Yukon natives. (Hayes in Nat. Geog. Mag., IV, 135.)
- SLANA**; river draining from Lake Suslota to Copper River. A native name, reported by Allen in 1885. Has also been written Slahna.
- SLATE**; creek tributary to the Middle Fork of the Koyukuk from the east near longitude 150°. Prospector's name, first published in 1899.
- SLIMS**; river tributary to Kluane Lake near latitude 61°, longitude 138½°. Name now first published.
- SNAG**; river tributary to the White from the west near longitude 140½°. Descriptive name, given by Peters and Brooks in 1898.
- SNAKE**; river tributary to the Nushagak River from the west. Local name, apparently suggested by the tortuous course of the stream.
- SOLUKA**; creek tributary to Katmai Creek near longitude 155°. Native name, obtained by the United States Geological Survey from Rev. A. Petelin in 1898.
- SOO CITY**; mining camp on South Fork of the Koyukuk near longitude 151°. Prospector's name, reported by the United States Geological Survey in 1899.
- SOONKAKAT**; village, and river tributary to the Yukon from the south in longitude 156°. Petrof in 1880 uses Soonkakak as the name of the village. Allen, in 1885, calls a stream which appears to be identical with this the Yukokakat. See Kakat.
- SOONKAKAT**; see Yuko.
- SOUTH**; fork of Birch Creek. Name published by the Coast Survey in 1895.
- SOUTH**; fork of the Koyukuk, tributary to the Koyukuk, near the Arctic Circle. Name published by the Coast Survey in 1899.
- SOZHEKLA**; river tributary to the Koyukuk from the north near longitude 151°. Native name, reported in 1885 by Allen, who writes it Sohjeklakakat in his text, page 99, and Sajeklakat on his map 4. It has also been written Sajahlakat.
- SPURR**; glacier in longitude 143°, near Skolai Pass. Named after J. E. Spurr, of the United States Geological Survey.

- SQUAW**; creek tributary to South Fork of the Koyukuk from the east near latitude 67°. Prospector's name, now first published.
- STIKINE**; strait and river debouching from the mainland near Wrangell. Supposed to be the native name of the river, and, since 1860 at least, written Stachine, Stahkeen, Stickeen, etc.; also, erroneously, Francis River and Pelly River. The above form, Stikine, has been adopted by both the Canadian and United States Boards on Geographic Names.
- STONY**; see Pyramid.
- SUKOSLEANTI**; river tributary to the Koyukuk from the west near its mouth. Native name, reported in 1885 by Allen, who writes it Succosleanty in his text, page 106, and Succosleanty on his map.
- SUNSHINE**; village or camp on the Klehini River near Chilkat River. Prospector's name.
- SUSHITNA**; mountain; river tributary to head of Cook Inlet; also Indian village and trading station of the Alaska Commercial Company, 50 miles north of the village of Tyonek. A native name long in use; has been written Suchitna and Sushetno. The above form, Sushitna, has been adopted by the United States Board on Geographic Names.
- SUSLOTA**; creek tributary to the Slana River. Native name, reported by Allen in 1885. In his text it is printed Suslota, and also, apparently erroneously, Sustota.
- SUWOROF**; see Naknek.
- TABLE**; mountain (6,000 feet) on headwaters of Koyukuk River in latitude 68°. Descriptive name, now first published.
- TAGISH**; lake and post-office east of Bennett Lake, Yukon district, Canada. Named Bove, in 1883, by Schwatka, after Lieutenant Bove of the Italian navy, but by Dr. Dawson called Tagish. The native name, according to Ogilvie, is Takone. The above name, Tagish, has been adopted by the Canadian Board on Geographic Names.
- TAIKO**; see Teslin.
- TAIYA**; see Dyea.
- TAKHIN**; river tributary to the Chilkat from the west, near head of Lynn Canal. Native name, reported by United States naval officers in 1880 as Takheen. Krause's map of 1882 has Takhin. Has also been called Tahini, Taklini. The above form, Takhin, has been adopted by the Canadian Board on Geographic Names.
- TAKHINI**; river draining from Kusawa Lake to the Lewes River. Native name, reported in 1883 by Schwatka, who writes it Tahk-heen-a. The above form, Takhini, has been adopted by the Canadian Board on Geographic Names.
- TAKONE**; see Tagish.
- TAKU**; arm, inlet, harbor, mountain pass, and river, near Juneau. Local name, first applied by Vasilief in 1848. Various written Taco, Tahko, Takou, etc. The above form, Taku, has been adopted by the Canadian Board on Geographic Names.
- TANADA**; creek and lake tributary to Copper River from the east near longitude 144°. Apparently a native name; reported by the United States Geological Survey in 1899.
- TANAKOT**; village on north bank of the Yukon, near mouth of the Melozi River. The Tenth Census (1880) gives as the name of a town near this locality Tanakhot-khaiak. On later maps this name appears as Tahmohkalony.
- TANANA**; large river of central Alaska, tributary to the Yukon; literally Tenan-ná or Tenan River, said to mean river of the mountain men. According to Allen its upper part is called Nabesná by the natives. It was known to the traders of the Hudson Bay Company as Gens des Buttes. Has been variously written Tananah, Tannanah, Tennanah, etc., but is now universally known as the Tanana.

- TANANA**; glacier in latitude 62° , longitude $142\frac{1}{2}^{\circ}$. Named by the United States Geological Survey in 1898.
- TARÁL**; village consisting in 1885 of two houses on the Copper River, at the mouth of the Chitina. Native name, reported by Allen.
- TATSHENSHINI**; river tributary to the Alsek River. Native name, reported in 1882 by Krause as Tatschanzhíni, and variously spelled. The above form, Tatschenshini, has been adopted by the Canadian Board on Geographic Names.
- TAZLINA**; glacier and river north of Prince William Sound, near latitude 62° ; also a lake called Tazlina or Pleveznie. Native name, reported by Geological Survey in 1898.
- TESLIN**; lake and river tributary to the Upper Yukon; often called Hootalinqua or Teslin. On early charts mistakenly called the Tahko. It is the Newberry River of Schwatka. The above form, Teslin, has been adopted by both the Canadian and United States Boards on Geographic Names.
- TETLING**; village (two houses), and river tributary to the Upper Tanana. Named in 1885 by Allen after an Indian.
- THRON DUICK**; see Klondike.
- TIKCHIK**; see Nushagak.
- TLEHINI**; see Klehini.
- TOK**; river tributary to the Tanana River from the south near longitude 143° . Native name, reported by Allen in 1885 as Tokái. According to Peters and Brooks, of the United States Geological Survey, this name, Tok, is in general use by both whites and Indians.
- TOKLAT**; river tributary to the Tanana from the south near longitude 151° . Native name, reported in 1885 by Allen, who spells it Toclat, and says its meaning is "dish water."
- TONSINA**; creek or river tributary to the Copper River from the west near latitude 62° . Native name, published on several maps. On recent maps it has been called Archer River.
- TOTSENBETNA**; river tributary to the Koyukuk from the north near longitude 149° . Native name, published by the Coast Survey.
- TOWER**; bluff on the Tanana River near longitude 144° . Named by Allen in 1885.
- TOWER BLUFF**; rapids in the Tanana near the above. Named by Allen in 1885.
- TOZI**; river tributary to the Yukon from the north near longitude $152\frac{1}{2}^{\circ}$. Native name reported by the Western Union Telegraph Expedition of 1867 as Towshe-cargut, and by Allen in 1885 as Tozikakat. See Kakat.
- TRAMWAY**; bar on Middle Fork of the Koyukuk River near longitude $150\frac{1}{2}^{\circ}$. Gold-producing bar located and named in the spring of 1899.
- TREAT**; island in Koyukuk River near longitude 156° . Named by Allen in 1885 after his classmate Lieut. Charles G. Treat, U. S. A.
- TUTLUT**; see Cantwell.
- TWELVEMILE**; creek tributary to the Middle Fork of the Koyukuk from the north near longitude $150\frac{1}{2}^{\circ}$. Apparently a descriptive name.
- UGAGUK**; river draining westward from Becharof Lake to Bristol Bay; also village at mouth of stream. An Eskimo name, reported by Lütke in 1828 as Ugaguk (Ougagouk) and by later Russians as Ugaguk or Igagik and since variously written Agouyak, Igiagik, Ugiagik, etc.
- UGASHIK**; see Becharof.
- UNION CITY**; mining camp at the mouth of South Fork of the Koyukuk River near longitude 152° . Prospector's name.
- VALDES**; glacier, narrows, port, and village at the head of Prince William Sound. According to Vancouver the port was named in the last century, by Fidalgo, Puerto de Valdes, and the spelling Valdes has been usually followed until quite recently, when the spelling Valdez has appeared. Valdes Narrows has also been called Stanton Narrows.

- VANCOUVER**; mountain in St. Elias region, named by the Coast Survey in 1875 after Capt. George Vancouver, who explored in this region in the last decade of the last century.
- VOLKMAR**; river tributary to the Tanana from the east near longitude 146°. Named in 1885 by Lieutenant Allen in honor of Col. William J. Volkmar, U. S. A.
- WADE**; creek in Fortymile mining district. Prospector's name, published by United States Geological Survey in 1899. Presumably named after a prospector, Jack Wade.
- WAITE**; island in the Koyukuk River. Named by Allen in 1885 "in honor of Miss Waite, of Washington City."
- WALKER**; fork of South Fork of Fortymile Creek. Miner's name, published by the U. S. Coast Survey in 1898.
- WALKER**; lake near latitude 67°, drained by the Kowak River. Name reported by Schrader of the United States Geological Survey in 1898. The lake is seemingly identical with Mena-kak-a-shah of Cantwell in 1885.
- WALKER**; station on north bank of the Yukon near the mouth of Tozi River, apparently identical with Nuklukayet.
- WALKER**; see NAKNEK.
- WALKERVILLE**; village near or in the Porcupine gold district. Name now first published.
- WEAVER**; town on the north bank of the Yukon at the mouth of Tanana River.
- WELLESLEY**; lake near international boundary, named by Hayes in 1891 after Wellesley College. Also mountain near the same, named by United States Geological Survey in 1898.
- WEST**; fork of Chandler River near latitude 67°. Name now first published.
- WEST KUSKAW**; see KUSAWA.
- WHITE**; pass at head of Lynn Canal, named in 1887 by Ogilvie after the Hon. Thomas White, minister of the interior (of Canada).
- WHITE**; river in Alaska and British Columbia tributary to the Upper Yukon. Discovered in 1850 by Robert Campbell of the Hudson Bay Company and by him named White on account of its color. According to Allen its Indian name is Natsiná.
- WHYMPER**; see HOSS.
- WILSON**; creek tributary to South Fork of the Koyukuk River from the north near longitude 150°. Prospectors name, reported by the United States Geological Survey in 1899.
- WINTHROP**; spur of mountain on north bank of the Koyukuk near longitude 156°. Also called Point Winthrop. Named in 1899.
- WISEMAN**; creek tributary to Middle Fork of the Koyukuk from the east near longitude 150°. Prospector's name, reported by United States Geological Survey in 1899.
- WOOD**; river draining from Aleknagik Lake to Nushagak River. Apparently so named by the United States Fish Commission in 1890.
- WRANGELL**; mountain east of Copper River near latitude 62°. Named by the Russians after Baron von Wrangell, whose branch of the family always used the double "l." Erroneously written Wrangle.
- YACHERGAMUT**; village on the Igushak River. Native name, reported by Geological Survey in 1898.
- YAHTSE-TAH-SHAH**; see St. Elias.

YAKUTAT; large bay in St. Elias region. Visited in 1786 by La Perouse, who named it Baie de Monti. In the same year Portlock named it Admiralty Bay. The Spaniards, a little later, following Portlock, called it Almiralty and Almirantazzo. Lisiansky in 1805 called it Jacootat and Yacootat. On the supposition that the bay was visited by Bering in 1741 it has been called by his name. Usage has, however, settled upon the native name Yakutat, and this form has been adopted by the United States Board on Geographic Names.

YUKO; river tributary to the Yukon from the south near longitude 156°. Native name, reported by Petrof in 1880 as Yukokakat; see Kakat. This stream appears to be identical with that called Soonkakat.

YUKON; principal river of Alaska. The headwaters of this river were known to traders of the Hudson Bay Company early in the century. Its lower part was explored by the Russians in 1837-38. Derzhabin founded the Russian post, Nulato, in 1841, and McMurray the English post, Fort Yukon, in 1847. The Eskimo name of the river, by which it was long known, is Kwik-pak (River-big), variously spelled Kvichpak, Kvikhpak, etc. The Indian name is Yukon, variously written Youcon, Yucon, etc., while one tribe of Indians, according to Allen, call it Niga To. Grewingk also gives the names Jukchana and Juna. The form Yukon has been adopted by the United States and Canadian Boards on Geographic Names.

ZAKATLATAN; village (population 39) on north bank of the Yukon near longitude 156½°. In the Tenth Census a village called Zakatlatan is located here on the south bank. In the Eleventh Census we have Sakataloden, supposed to be the same place. On late maps it is Saghadellautan.

INDEX.

A.	Page.
Abercrombie, Capt. W. R., exploration in Alaska by.....	343, 399, 400, 402
Adams, G. I., and Taff, J. A., paper on geology of Eastern Choctaw coal field, Indian Territory, by.....	257-311
Adkins, C. G., coal-mining operations in Indian Territory by.....	302, 304
Alaska, acid igneous rocks in.....	430
animals in.....	387-388, 415, 459-460
Archean rocks in.....	356-357, 367, 433, 471-472
basic volcanic rocks of.....	429-430
birds in.....	388, 415, 460
Carboniferous rocks in.....	359.
climate and seasons in.....	367, 369, 370, 431, 433
coal in.....	388, 412-414, 458-459
Coast Range of.....	382-383, 485-486
copper in.....	345
correlation of geologic formations of.....	377-382, 437-439, 482
Cretaceous rocks in.....	367, 370, 433, 476-477
Devonian rocks in.....	367, 369, 370, 433, 476
distances in (tables).....	450
early explorations in.....	340-343, 400-401, 431, 433
effusive rocks of.....	362-363, 364
fish in.....	415, 460
fossils from.....	439-440
game in.....	387-388, 415, 459-460
geographic names in.....	437-509
geologic maps of.....	356, 404
geologic reconnaissances in.....	331-486
glacial phenomena in.....	364-365
gold in.....	373-377, 436-437, 482-485
ground ice in.....	366
igneous rocks of.....	360-362, 364, 430, 479-482
intrusive rocks of.....	360-362, 370
insects in.....	460
Jurassic rocks and fossils of.....	367,
370 (note), 431, 433, 439, 440	
lead ore in.....	482
maps of.....	338,
356, 374, 380, 400, 404, 448, in pocket	
mineral resources of.....	373-383, 436-439, 482-486
Miocene rocks of.....	372
names of geographic features of.....	487-509
native inhabitants of.....	388-390, 457-458
pack trains, use of, in.....	418
Pleistocene deposits of.....	363-364,
367, 371-372, 433, 478-479	
railway routes possible in.....	386-387
routes, trails, and methods of travel	
in.....	383-387, 415, 418, 453-457
Silurian rocks in.....	358, 367, 368, 433, 474-475
Tertiary rocks of.....	362-363,
367, 370, 372, 433, 477, 478	

Alaska—Continued.	Page.
timber and vegetation in.....	387, 414, 460-461
topographic maps of portions of.....	338,
346, 355, 374, 380	
trails and routes in.....	383-387, 415-418, 453-457
Triassic rocks and fossils of.....	420-427,
431, 433, 439, 440	
vegetation in.....	387, 414, 460-461
volcanic rocks in.....	371, 429-430, 481-482
volcanic tuff in.....	365-366
white inhabitants of.....	390-391, 457, 458
Alaskan Range, features of.....	372
Algonkian rocks, Rico Mountains.....	25, 26, 37-41
Allen, Lieut. H. T., explorations in Alaska by.....	341, 400, 410
Allen River, Alaska, route along.....	456
Alluvial fans, Rico Mountains, Colorado.....	162-163
Allyn Gulch, Rico Mountains, Colorado, glacial cirque near.....	156
Alsek River basin, Alaska, features of.....	348-349
Alunite, analyses of.....	94
Amphibolite-schist, Alaska, character and occurrence of.....	472-473
Analyses, alunite rocks.....	94
banatite.....	82
coal.....	267, 306-311, 325-329
diorite-porphry.....	86
monzonite.....	82
monzonite-porphry.....	86
quartz-monzonite.....	86
Animals, Alaska.....	387-388, 415, 459-460
Aplite, metasomatic alteration of.....	246-247
Archean rocks, Alaska.....	356-357, 367, 433, 471-472
Arkansas, maps showing area of Camden coal field in.....	320, 322
report on Camden coal field of.....	313-329
Arkansas Valley region, Indian Territory, topography of.....	267
Aspen Creek, Colorado, landslide areas on.....	145
Atlantic Cable claim, Rico, Colo., section at.....	27, 42
Atoka formation, Indian Territory, features of.....	273-274
Augite-vogesites, Rico Mountains.....	32, 88
Aztec Gulch, Rico Mountains, Colorado, view of alluvial fan at mouth of.....	162

13.

Baby Creek, Alaska, granite on.....	480
route along.....	454
Backbone anticline, Indian Territory, features of.....	283-284
Backbone fault, Indian Territory, course and general features of.....	285
Baker Creek, Alaska, features of.....	352
Baker, Marcus, list of Alaskan geographic names prepared by.....	487-509

	Page.		Page.
Banatite, analyses of	82	Brogger, W. C., rock name "monzonite" proposed by	79
occurrence of, Rico Mountains	30-31, 79-82	Brooks, A. H., cited on Alaskan topography and geology	351-352, 362, 367, 369, 435, 436
Barnard, E. C., Alaskan exploration by	343	exploration in Alaska by	343, 400
Basic dikes, Alaska	471-472, 481-482	report of reconnaissance in Alaska by	331-486
Basic dike rocks, Rico Mountains	31-32, 87-90	Brown, Ed., acknowledgments to	337
Bazanof, exploration in Alaska by	400	Bryan Creek, Alaska, gold on	485
Beardslee, Capt. L. A., Alaskan exploration by	340	Bryan, L. W., acknowledgments to	265
Becker, G. F., cited on solution of gold in thermal waters	249	Burlingame & Co., assays made by	448
Bedding faults, Rico Mountains, features of	107-110	Burnett Creek, Colorado, landslide areas near	141-143
origin of	110-112		
Bergman, Alaska, faulting in sandstone near	469	C.	
location and importance of	484	Cahill, Joseph, acknowledgments to	337
view of	456	calcareous spring deposits, Rico Mountains	163-164
Bergschlund, cirque sculpturing by means of	173, 178, 185-187, 190	Caliche netted with silica Boulder Hot Springs, Montana	242-243
Bettles, G. C., acknowledgments to	418	Calico Peak, Colorado, porphyry of	87
Bettles series of rocks, Alaska, character and occurrence of	475	solitary action at	35, 91-93
Bighorn Mountains, Wyoming, glacial sculpture in	165-190	view of	32
Birch Creek schists, Alaska, age and correlation of	365, 433	Camden coal field, Arkansas, age of coal-bearing rocks of	320-321
Birds, Alaska	388, 415, 460	coal of	322-329
Blackhawk mine, Rico Mountains, Colorado, fault at	116-118	location of	319
Blackhawk Peak, Colorado, landslide areas near	144-145	maps of	320, 322
view from	18	rocks of	321-322, 325-329
views of	21, 22, 24	sections in	321, 322
Boggy shale, Indian Territory, features of	278-279	topography of	319-320
Bokoshe syncline, Indian Territory, coal bed in	295	Canadian Development Company, acknowledgments to	448
features of	284	Cantwell conglomerate, Alaska, age and correlation of	367, 433
Boulder Hot Springs, Montana, alteration of rocks by action of water at	244-247	Cantwell River, Alaska, features of	352
faulting of vein at	249	Carbonic acid exhalations, Rico Mountains, Colorado	33, 164, 165
fractures and fissure filling at	238-240	Carboniferous fossils, Rico Mountains, Colorado	48, 59, 66
gold and silver content of veins at	248-249	Carboniferous rocks, Alaska	367, 369, 370, 431, 433
jasper and quartz veins at	241-245	Rico Mountains, Colorado	27-28, 47, 66
location and general features of	245-246	Cavanal coal, Indian Territory, occurrence and character of	292-294
map of	238	Cavanal coal-mining district, Indian Territory, operations in	300
metasomatic alteration of rocks at	246-247	Cavanal Coke and Railway Company, Indian Territory, operations of	301
microscopic petrography of altered rocks and vein filling at	252-255	Cavanal mine, Indian Territory, vertical section showing coal bed and associated rocks in	292
mineral vein formation at	245-255	Cavanal Mountain, Indian Territory, syncline at	282
ore deposition at	249-252	Cavanal syncline, Indian Territory, coal beds in	289, 291-292, 293, 294-295
origin of veins forming material at	248	features of	282
quartz and jasper veins at	234-235	Cave Spring, Nevada, view* of lake beds at	24
recent movement or faulting of vein at	249	Cereis nevadensis, a fossil plant from Nevada, description of	217-218
rock decomposition affected by	244-245	figure of	218
theory of ore deposition at	249-252	Chance, H. M., survey of Choctaw coal field, Indian Territory, made by	263-264
vein filling at	240-244, 248		
view of	244		
water of	247-248		
Brazil anticline, Indian Territory, coal beds in	291		
features of	282-283		
Brocu, George, Alaskan exploration by	341		

	Page.		Page.
Chandler Lake, Alaska, quartzite-schist at	474	Choctaw Nation, Indian Territory, geology of coal field in	257-311
Chandler River, Alaska, amphibolite-schist on	472-473	map of	264
basalt on	481-482	Choctaw, Oklahoma and Gulf Railroad Company, Indian Territory, coal-mining operations of	300, 304
course and character of	464, 466-467	Chrysobalanus pollardiana, a fossil plant from Nevada, description of	216
diabase on	479-480	figure of	222
distances along (tables)	450	Cinchonidium turneri, a fossil plant from Nevada, description of	218
explorations on	449	figure of	222
features of	466-467	Cirques, glacial, mode of recession of walls of	178-179
gold on	482-483	origin of	173-175, 178-179, 185-190
granite on	471	Clayton Valley, Nevada, view of lake beds east of	200
lacustrine silts along	479	Climate and seasons, Alaska	388, 412-414, 458-459
map of portion of	448	Cloud Peak, Wyoming, map of glaciated region near	176
mica-schist on	473-474	Coal, Alaska	382-383, 485-486
natives of region near	457	analyses	207, 306-311, 325-329
routes and trails along	454, 455, 456	Arkansas	322-329
view of rapids on	450	Indian Territory	285-296, 306-311
view up	464	Nevada	206-207
Chandler River Basin, Alaska, animals in	459-460	Coal-bearing rocks, Camden coal field, Arkansas	320-322
Bettles series of rocks in	475	Coal field in Indian Territory, geology of	257-311
climate in	458-459	Coal field of southwestern Arkansas, preliminary report by J. A. Taff on	313-329
routes and trails in	453-455	Coal mining, Indian Territory, history, extent, and detailed operations of	297-305
till deposits in	478	Coast Range of Alaska, features of	345
timber and vegetation in	460-461	Colorado, geologic investigations in	7-165
topography and drainage of	464-466	Conglomerates, Rico Mountains, Colorado	38-39
West Fork series of rocks in	475-476	Contact metamorphism, Rico Mountains, Colorado, features of	32, 91-92
Chandler and Koyukuk rivers, Alaska, report of reconnaissance by F. C. Schrader on	441-486	Cooper, E. J., aid by	339
map of portions of	448	Copper, Alaska	377-382, 437-439, 482
Chandler Rapids, Alaska, location and features of	465	Copper River, Alaska, features of valley of	408-409
view of	450	trails along	415-416, 417
C. H. C. Hill, Colorado, Carboniferous limestones at	54	Copper River district, Alaska, climate and seasons in	412-414
faults at	128, 148	Correlation of geologic formations of Alaska	367, 431-433
landslide areas at	137-138, 140-141, 145, 146, 148	Creadon River, Alaska, position of	351
present landslide action at	139-140	Crescent Coal and Mining Company, Indian Territory, operations of	300, 304
views of	140, 142, 144, 146	Cretaceous lavas, Alaska	481
Chilkat Indians, Alaska, notes on	388-389	Cretaceous rocks, Alaska	367, 370, 433, 476-477
Chilkat River, Alaska, features of	347-348	Rico Mountains	77-78
Chislechina River, Alaska, drainage area of	411	Cross, Whitman, cited on geology of areas in Colorado	85, 93, 95, 113, 152
gold mining on	437	Cross, Whitman, and A. C. Spencer, paper on geology of Rico Mountains by	7-165
trails along	417	Cushing, H. P., explorations in Alaska by	341
Chitina River, Alaska, features of mountains south of	410	cited on Alaskan geology	362
features of valley of	409		
geology of region near	422-425		
trails along	416-417		
Chitina River and Skolai Mountains, Alaska, report of reconnaissance of	393-440		
Chitstone limestone, Alaska, age and correlation of	433, 434		
occurrence and character of	426, 427		
faulting and folding in	427-429		
view showing folding in	428		
Choctaw Coal and Mining Company, Indian Territory, operations of	301, 304		
Choctaw coal fields, Indian Territory, maps of	280, in pocket		
Choctaw fault, Indian Territory, course and general features of	284-285		

Dall, W. H., cited on Alaska and Alaskan geology

 340, 372, 377, 400, 481

 fossils from Nevada examined by 204

	Page.		E.	Page.
Dall River, Alaska, trail along.....	455	Eagle City, Alaska, map showing reconnaissance from Pyramid Harbor to		338
Dalton, Jack, Alaskan exploration by ..	341, 342	report on reconnaissance from Pyramid Harbor to		331-391
Dalton House, Alaska, buildings at	338, 391	Eakins, L. G., analyses by		82, 93-94
Dalton Range, Alaska, features of	345	Eastern Choctaw coal field, Indian Territory, Arkansas Valley region of ..		267
Dalton trail, Alaska, course and general features of	338, 384	boundaries of		263
Dana, E. S., cited on origin of thiolite ..	202	composition and adaptability of coals in		306-311
Darling Ridge, Rico Mountains, Colorado, landslide areas at and near	132, 136, 150	descriptions of maps of		254-265
rocks of	25, 30, 31, 83, 91	distribution of coal in		285-296
view of	130	geology of		257-311
Davidson, George, work on Alaska by	340	highland plain of		268-270
Dawson, G. M., Alaskan exploration by ..	341	literature of		263-264
cited on Alaska	361, 370, 378, 387, 389	lowland plain of		267-268
Deadwood fault, Rico Mountains, features of	114-115	maps of		280, in pocket
Deadwood Gulch, Colorado, evidences of glacial action at	157, 158	mining development in		296-305
fault at	114-115	mountains of		270-271
Delta River, Alaska, features of	352	Ouachita Mountains region of		266
Deformation, definition of	103	stratigraphy of		271-279
Deposition of ores by hot springs, theory of	249-252	structure of		266, 279-285
Devonian rocks, Alaska	367, 369, 370, 433, 476	summary of coal-mining operations in		304-305
Rico Mountains, Colorado	26-27, 41-47	topography of		265-271
Dibase, Alaska	479-480	Eastern Coal and Mining Company, Indian Territory, operations of		297, 298, 304
Dikes, basic, Rico Mountains, Colorado, occurrence and character of	31, 32, 87-90	Effusive rocks, Alaska		362-363, 364
Diorite-porphry, analysis of	86	Emmons, S. F., cited on geologic history of Rocky Mountain region		37, 78
Dioritic rock, Horace Mountain, Alaska ..	480-481	Endlich, F. M., cited on origin of certain metamorphic rocks in Colorado ..		37
Dietrich River, Alaska, amphibolite-schist on	473	geologic work in Colorado by		17, 18
course and general features of	468-469	Enterprise mine, Colorado, section at ..		52
distances along table	452	Ernestine Creek, Alaska, gold on		436-437
explorations of	449	Esmeralda formation, Nevada, age of ..		203-205
Dolores formation, Colorado, definition and description of	67-68	character and distribution of		198-199
distribution and occurrence of	72-73	coal beds of		206-207
igneous intrusions in	105	fossil fish from		223-226
lower division of	68-71	fossil plants of		209-222
sections of	68-70	location of		197
thickness of	66	map showing areal distribution of ..		198
upper division of	71-72	relation of adjacent lava flows to ..		205-206
Dolores Mountain, Colorado, faults at and near	115-116	sections of		199, 200-203
landslide areas at	143-144, 145	sulphur deposits of		207-208
section at	58	thickness of		199-203
views of	21, 22, 24, 26	vein deposits of		206
Dolores Plateau, features of	19, 20, 23	views showing		200, 202, 204, 206, 208
Dolores River, Colorado, course and character of	20, 21	Expectation Mountain, Colorado, view of ..		148
landslide dam on	138-139			
Dolores Valley, Colorado, features of	20, 23			
view of	22			
Donjek River, Alaska, features of	350, 351			
views on	354			
Drake, N. F., survey of coal fields of Indian Territory made by	264			
Dryopteris gleichenoides, a fossil plant from Nevada, description of	211			
figure of	222			
Dunn, R. L., Alaskan exploration by	343			
cited on gold prospects in Shorty Creek district, Alaska	373-374			
Dutton, C. E., cited on Permo-Carboniferous rocks of Western States	64			

	Page.
<i>Ficus lacustris</i> , a fossil plant from Nevada, description of	215-216
figure of	222
Fish, Alaska	415, 460
Fish, fossil, from Nevada, description of	223-224
figure of	226
Fissures and fissure filling, Boulder Hot Springs, Montana	238-240
Fort Smith and Western Railway Company, coal-mining operations in Indian Territory by	303, 304
Fort Yukon, Alaska, determination of astronomic position of	449
trails from	453-454, 456
Fortymile gold region, Alaska, operations in	376-377
Fortymile Post, Alaska, location and importance of	391
Fortymile River, Alaska, features of	353
gold on	376-377
Fortymile series, Alaska, age and correlation of	367, 433
Fossil fish from Esmeralda formation, Nevada	223-226
Fossil plants of the Esmeralda formation, Nevada	209-222
Fossils, Mesozoic, Alaska	439-440
Carboniferous, Colorado	48, 59, 66
Fourche Maline Valley, Indian Territory, geologic structure in	288
Frazer, S. M., acknowledgments to	338
G.	
Galena, Alaska	482
Game, Alaska	387-388, 415, 459-460
Garvey, D. D., acknowledgments to	338
Gas springs, Rico Mountains	165
Gastaldi, B., cited on origin of glacial cirques	173
Geographic names, Alaska, list of	487-509
George, R. D., aid by	16
Gerdine, T. G., Alaskan surveys by	447, 449, 450
Geroe Creek, Alaska, route along	454
Gilbert, G. K., cited on geology of Western United States	64, 94
definition of deformation by	103
Girty, G. H., Paleozoic fossils from Alaska determined by	428, 431, 448, 476
Permo-Carboniferous (Rico) fossils from Colorado determined by	60, 65
Glacial cirques, mode of recession of walls of	178-179
origin of	173-175, 178-179, 185-190
Glacial motion, cause of	185-190
Glacial phenomena, Alaska	364-365
Glacial sculpture in the Bighorn mountains, Wyoming, paper by F. E. Matthes on	167-190
Glaciation, Rico Mountains, Colorado	35, 156-159
Glave, E. J., Alaskan exploration by	341, 342
Gleichenia obscura, a fossil plant from Nevada, description of	210
figure of	222
Gneissic series of rocks, Alaska, age and character of	356-357, 367, 433
Gold, Alaska	373-377, 436-437, 482-485

	Page.
Gold and silver contents of veins at Boulder Hot Springs, Montana	248-249
Goodpaster River, Alaska, features of	352
Goodrich, H. B., Alaskan exploration by	342
Gowen coal-mining district, Indian Territory, operations in	297
Gowen mine, Indian Territory, thickness and character of coal beds at	287
Grand View smelter, Rico Mountains, Colorado, fault near	120-122
Granite, Alaska, occurrence and character of	360-361, 471-472, 480
Boulder Hot Springs, Montana, encrustation, alteration, and decomposition of	241-242, 244-247, 252-253
Granite Creek, Alaska, trail along	451
Grave Creek, Alaska, trail along	454
Greenstone-schists, Alaska, age and character of	358, 367, 433
Ground ice, Alaska, occurrence of	366
Gypsum deposits, Rico Mountains, occurrence of	49, 53
origin of	111

H.

Haines, Alaska, location and importance of	390
Haley, J. J., acknowledgments to	338
Hanus, G. C., Alaskan exploration by	340
Harper, Arthur, Alaskan exploration by	340
Harris, G. D., cited on geology of southwestern Arkansas	320-321
Hartshorne coals, Indian Territory, occurrence, character, and general features of	287-290
vertical sections of	287, 289
Hartshorne sandstone, Indian Territory, features of	274-275
section of	274
Hartshorne, W. O., coal-mining operations in Indian Territory by	303, 304
Hayden, F. V., geologic work in Colorado done by	15, 17-18
Hayes, C. W., cited on Alaskan geology	345, 350, 357, 372, 380, 389, 417, 427, 434, 435, 438
explorations in Alaska by	342, 380, 400-401
Hayes River beds, Alaska, age and correlation of	367, 433
Hawkins, C. J., acknowledgments to	448
Heavener anticline, Indian Territory, coal beds in	289-290
features of	281-282
Heilprin, Angelo, cited on origin of ash deposit in Alaska	365 (note)
Helland, A., cited on origin of glacial cirques	173
Hermosa formation, Animas section of	48-49
correlation of	59
fossils of	48, 57, 59, 66
lithology of	48
lower beds of	50-53
medial division of	53-57
Rico section of	49-59
sections of	52, 53, 55, 56, 58
thickness of	49
upper division of	57-59

	Page.		Page.
Koyukuk River—Continued.		Last Chance fault, Rico Mountains, Colorado, features of.....	119-120
Cretaceous rocks on	476-477	Lavas, Alaska, occurrence and character of.....	481-482
distances along (table).....	450-452	Lead ore, Alaska.....	482
distances along Middle Fork of (table).....	453	Leuciscus turneri, a fossil fish from Nevada, description and figure of.....	223-226
distances along South Fork of (table).....	453	Libbey, William, Alaskan exploration by.....	341
gold on.....	483-485	Limestone, Alaska.....	475
map of portion of.....	448	Rico Mountains, Colorado.....	45-47
natives of region near.....	457-458	Lindgren, Waldemar, cited on the term "granodiorite".....	95 (note)
Pleistocene gravels along upper course of.....	478	notes on microscopic petrography of rocks at Boulder Hot Springs, Montana, prepared by.....	252-255
routes and trails along.....	455	Little Missouri River, Arkansas, section on.....	322
view on Middle Fork of.....	468	Long Mountain, Indian Territory, vertical sections at.....	287, 288
views of.....	456, 458, 468, 478	Lowe, P. G., Alaskan exploration by.....	343
white population on and near.....	458	Lowe River, Alaska, geology of region near.....	419
Koyukuk River Basin, Alaska, animals in.....	459-460	Lucas, F. A., cited on fossil fish from Nevada.....	204
climate in.....	459	description of fossil fish from Nevada by.....	223-226
Eocene rocks in.....	477	Luigi Amedeo, Prince, Alaskan exploration by.....	342
gold in.....	483-485	Lynn Canal, features of.....	344
lacustrine silts and gravels in.....	479	native inhabitants of region near.....	388-389
profile across.....	468		M.
river gravels in.....	478	McAlester, Indian Territory, anticline at.....	280-281
routes and trails in.....	455-457	McAlester coal, Indian Territory, occurrence and character of.....	291-292
timber and vegetation in.....	460-461	McAlester Coal and Mineral Company, Indian Territory, operations of.....	297, 304
topography and drainage of.....	464, 467-468	McAlester shale, Indian Territory, features of.....	275-276
Koyukuk River Valley, profile across.....	468	McAlester syncline, Indian Territory, features of.....	280-281
Koyukuk and Chandalar rivers, Alaska, map of portions of.....	448	McArthur, J. J., Alaskan exploration by.....	342
report of reconnaissance by F. C. Schrader on.....	441-486	McCarthy Creek, Alaska, geology of region near.....	427-428
Krause, Arthur, Alaskan exploration by.....	340	McCarthy Creek shales, Alaska, age and correlation of.....	433
Kuskulana Pass, geology of region near.....	423-424	faulting and folding in.....	427-429
Kuskulana River, Alaska, explorations on.....	431	occurrence and character of.....	426-427
geology of region near.....	423-424, 431-432	McClellan, R. F., aid by.....	405
Kuskulanashales, Alaska, age and character of.....	423, 424, 433	McConnell, R. G., cited on geology of parts of Alaska.....	357 (note), 372, 476
	L.	McElmo formation, Colorado, correlation of.....	77
Laccolithic mountains of Colorado, comparison of Rico Mountains with.....	94-96	definition of.....	76
Lake Creek, Alaska, trail along.....	454	description and occurrence of.....	76-77
Lake Klwane, deformation of Pleistocene deposits at head of.....	371-372	thickness of.....	66
features of.....	350-351	McKinley Creek, Alaska, gold on.....	375, 485
Lake quartzite schist, Alaska, occurrence and character of.....	474-475	McNeer, A. H., acknowledgments to.....	339
Landslides, Rico Mountains, Colorado, age of.....	147-148	Mahutzu River, Alaska, features of.....	352
character of.....	146	Martin, Thomas, acknowledgments to.....	339
occurrence of.....	129-151, 161	Matanuska series of rocks, Alaska, age and correlation of.....	367, 433
origin of.....	149-151	Matthes, F. E., paper on glacial sculpture in the Big Horn Mountains by.....	167-193
relations of faults to.....	148-149		
topographic and other relations of.....	146-147		
Landslip Mountain, Colorado, landslide areas at.....	143, 150		
La Plata folio of geologic Atlas of the United States, reference to.....	19		
La Plata formation, Colorado, correlation of.....	76		
definition of.....	73-74		
description of.....	74-75		
distribution and occurrence of.....	75-76		
section of.....	75		
thickness of.....	66		
La Plata Mountains, general features of.....	19, 100		

	Page.		N.	Page.
Mayberry coal-mining district, Indian Territory, operations in.....	301	Nabesna Range, Alaska, geology of.....		429
Meek, F. B., cited on Permo-Carboniferous.....	47	Nabesna River, Alaska, copper deposits on and near.....		381, 438
Melanocratic dike rocks, Rico Mountains.....	87-88	course and drainage area of.....		411
Mendenhall, W. C., cited on Alaskan geology.....	357	features of.....		351, 352
Mentasta Range, Alaska, features of.....	411	Naknek series of rocks, Alaska, age and correlation of.....		317, 433
Merriam, J. C., cited on age of Esmeralda lake beds, Nevada.....	203-204	Nagaief, exploration in Alaska by.....		400
Mesozoic fossils, Alaska.....	439-440	Names, geographic, Alaskan (list).....		487-509
Metalliferous veins, theories of origin of.....	249-252	Nasina series of rocks, Alaska, age and correlation of.....		367, 433
Metamorphism of rocks, Rico Mountains.....	32	Native inhabitants, Alaska.....		388-390
Metasomatic alteration of rocks by action of hot springs.....	246-247	Nelly Bly vein, Rico Mountains, Colorado, fault at.....		116, 118-119
Mexican Gulf Coal and Transportation Company, Indian Territory, operations of.....	300, 304	Nevada, analysis of coal from.....		207
Mica-schist, Alaska, character and occurrence of.....	473-474	coal beds in.....		207
Milby & Dow, coal mining operations in Indian Territory by.....	300, 304	Esmeralda formation in.....		191-226
Milton, Indian Territory, anticline near.....	283	fossil plants from.....		206-222
Mineral spring deposits, Boulder Hot Springs, Montana.....	233, 244, 252-254	sulphur deposits in.....		207-208
Rico Mountains, Colorado.....	163-165	Newman Hill, Colorado, Carboniferous rocks at.....		50-52
Mineral vein formation at Boulder Hot Springs, Montana, paper by W. H. Weed on.....	227-255	contact deposits at.....		108-110
Mineral veins, Boulder Hot Springs, Montana, alteration of rocks near.....	245-247	glacial accumulations at.....		158
filling of.....	240-244	intruded igneous sheet at.....		30, 104
gold and silver content of.....	248-249	landslide areas at.....		143-144
microscopic petrography of filling of.....	252-255	ore-bearing horizon at.....		50
nature of.....	234	views of.....		21, 22, 26
origin of.....	234, 248	Nigger Baby Hill, Colorado, faults at.....		118, 119
recent movement or faulting on.....	249	Nikolai copper vein, Alaska, features of.....		437
theory of ore deposition in.....	249-252	Nikolai greenstone, Alaska, age and correlation of.....		433
Mission Creek series of rocks, Alaska, age of.....	370	copper vein in.....		435, 437
correlation of.....	367, 370, 433	occurrence and character of.....		425, 426
Mitchell Basin, Indian Territory, vertical section showing coals and associated rocks in.....	291	Nilkoka beds, Alaska, age and correlation of.....		367, 433
Mitchell Basin, coal mining district, Indian Territory, operations in.....	300	Nilkoka River, Alaska, features of.....		352
Monocline Thee, Nevada, view of.....	208	Nivation, processes and effects of.....		179-185
Monroe, C. E., assays made by.....	248	Nizina Glacier, Alaska, features of.....		406
Montana, mineral vein formation at hot springs in.....	227-255	geology of region near.....		428
Monzonite-porphry, analyses of.....	86	views of.....		406, 408
occurrence of, Rico Mountains.....	31, 83-86	Nizina River, Alaska, exploration on.....		406-407
Monzonites, analyses of.....	82	features of.....		409-410
occurrence and character of, Rico Mountains, Colorado.....	30-31, 79-82, 91	geology of region near.....		425-429, 432, 434
Mount Blackburn, Alaska, features of.....	411	Nulato, Alaska, coal beds near.....		485-486
Mount Drum, Alaska, features of.....	410	Nulato sandstone, Alaska, age and correlation of.....		367, 433
Mount Elliott, Colorado, glacial deposits at.....	158, 161	occurrence of.....		478
Mount Regal, Alaska, location of.....	411	Nushagak beds, Alaska, age and correlation of.....		367, 433
Mount Sanford, Alaska, features of.....	410	Nutzotin Mountains, features of.....		346, 411
Mount Wrangell, Alaska, features of.....	410	geology of.....		429
Muir, John, Alaskan exploration by.....	340	Nutzotin series of rocks, Alaska, age, character, and correlation of.....		359-360, 367, 369, 433
Myrtle Creek, Alaska, gold on.....	483-485	gold in.....		373
views on.....	468, 476			

O.

O'Connor, J., acknowledgments to.....	338
O'Connor Glacier, location of.....	338
view of.....	350
O'Connor River, features of.....	349
Ogilvie, William, Alaskan exploration by.....	341
Oklune series of rocks, Alaska, age and correlation of.....	367, 433

	Page.
Ola Coal and Mining Company, Indian Territory, operations of	298, 304
Orca series of rocks, Alaska, age and correlation of	367, 433
Ore deposition by hot springs, theory of	249-252
Ore deposition, Rico Mountains	33-34
Ouachita Mountains region, Indian Territory, geologic structure of	266
Ouachita River, Arkansas, section on	322
Ourray limestone, Rico Mountains	41-42, 45-47
Owen, D. D., cited on geology of southwestern Arkansas	320, 323-324
Ozark Coal and Railway Company, Indian Territory, operations of	302, 304
P.	
Pack trains, Alaska, use of	418
Paige, Jason, aid by	16
Palisade conglomerate, Alaska, age and correlation of	367, 433
Panama coal, Indian Territory, character of	289
equivalents of	288-289
Panola coal mining district, Indian Territory, operations in	298, 302
Papoose Gulch, Colorado, glacial deposits at	158, 161
Peale, A. C., cited on geology of a portion of Colorado	65
Peavey, Alaska, location and importance of	484
view of	456
Permo-Carboniferous rocks of Rico Mountains, Colorado	27-28, 59-66
Peters, W. J., work in Alaska by	337, 343, 400
Petroff, Ivan, cited on Alaska	340 (note)
Petrography, igneous rocks of Rico Mountains, Colorado	79-88
Phillip, G. S., work in Alaska by	337
Pirsson, L. V., cited on occurrence of monzonite-porphry	86
Plants, fossil, of the Esmeralda formation, Nevada	209-222
Pleasant Camp, Alaska, location of and buildings at	338, 390
view of	344
Pleistocene deposits, Alaska, occurrence of	363-364, 367, 371-372, 433, 478-479
Pocahontas coal-mining district, Indian Territory, operations in	299
Pocola coal-mining district, Indian Territory, operations in	302-303
Porcupine beds, Alaska, age and correlation of	367, 433
Porcupine Creek, Alaska, gold on	374-376
Porcupine gold district, Alaska, gold in	374-376
map of	374
Porphyries, analyses of	86
occurrence of, Rico Mountains	29, 30, 83-91
sofataric alteration of	32-33, 91-93
Portage Creek, Alaska, view of	450
Poteau coal-mining district, Indian Territory, operations in	300-301
Poteau Mountain, Indian Territory, syncline near	280

	Page.
Poteau syncline, Indian Territory, coal beds in	290, 292, 295
features of	280
Potter mine, Indian Territory, vertical section showing coals and associated rocks in	290
Pratt, J. F., work on Alaska by	340
Prince William Sound, Alaska, climate of	412
Purinton, C. W., geologic work in Colorado by	16
Puzzle mine, Rico Mountains, Colorado, landslide areas near	134-135, 138, 146
Pyramid Harbor, Alaska, map showing route of reconnaissance to Eagle City from	338
report of reconnaissance to Eagle City from	331-391

Q.

Quartz and jasper veins, Boulder Hot Springs region, Montana	234-235
Quartz Creek, Alaska, geology of region near	419
gold on	436-437
Quartz-monzonite, Rico Mountains, analyses of	86
occurrence of	30-31, 79-82
Quartzite-schist, Alaska	474-475
Quartzites, Rico Mountains	38, 39, 40-41, 43-45
Quercus argentum, a fossil plant from Nevada, description of	215
figure of	222
Quercus turneri, a fossil plant from Nevada, description of	214-215
figure of	222

R.

Rail Creek, Alaska, gold on	465
Railway routes in Alaska	386-387
Rainy Hollow, Alaska, copper deposits at	378-379
settlement at	390-391
Rampart series of rocks, Alaska, age and correlation of	367, 433
Ransome, F. L., geologic work in Colorado by	16
Rapids schist, Alaska, occurrence and character of	473-474
Redoak coal-mining district, Indian Territory, operations in	298
Reid, H. F., Alaskan exploration by	341
cited on Alaskan geology	362, 369, 370
Rhus nevadensis, a fossil plant from Nevada, description of	218-219
figure of	222
Richardson, G. B., acknowledgments to	265
Rickard, T. A., cited on geology of portions of Colorado	42, 53, 108-109
geologic work in Rico Mountains, Colorado, by	18-19
Rico, Colorado, strata exposed near	98
Rico-Aspen mine, Colorado, section at	52-53
Rico dome, Colorado, erosion of	34-35, 152-159
origin of	112-114
profile sections of	102
structure of	98-128
view of	102

	Page.		Page.
Rico formation, Colorado, correlation of.....	64-66	Salix angusta, a fossil plant from Nevada, description of.....	212
definition of.....	59-60	figure of.....	222
description of.....	60-62	Salix vaccinifolia, a fossil plant from Nevada, description of.....	212-213
distribution of.....	62-64	figure of.....	222
fossils of.....	66	Sandstone Mountain, Colorado, landslide areas near.....	145
section of.....	62	section of.....	55-56
Rico Mountains, Colorado, Algonkian rocks of.....	25, 26, 37-41	view of.....	28
alluvial fans in.....	162-163	views from.....	128, 130, 140
Carboniferous rocks of.....	27-28, 47-66	San Juan Mountains, Colorado, features of.....	20, 99-100
comparison of laccolithic mountains with.....	94-97	Sansbois Mountain, Indian Territory, geologic structure near.....	288
conglomerates in.....	38-39	Sansbois syncline, Indian Territory, coal beds in.....	287-289, 291, 293-294, 295
contact metamorphism in.....	32	features of.....	283
Cretaceous rocks of.....	77-78	Savanna formation, Indian Territory, features of.....	276-278
Devonian rocks of.....	26-27, 41-47	Schanz, A. B., Alaskan exploration by.....	341
dikes in.....	31-32, 87-90	Scheerer, T., analysis by.....	82
drainage system of.....	20	Schists, Alaska.....	473-475
erosion in.....	34-35, 152-156	Rico Mountains, Colorado.....	39-40, 44-45
faults and fissures in.....	23-24, 105-112, 114-128	Schrader, F. C., cited on Alaskan geography and geology.....	345, 372, 410, 419, 435
ferruginous deposits in.....	164-165	exploration in Alaska by.....	342, 402-403
gas springs in.....	165	report of reconnaissance along Chandlar and Koyukuk rivers, Alaska, by.....	441-486
general description of.....	19-21	Schuchert, Charles, Alaskan fossils identified by.....	359
geologic map of.....	In pocket	Schwatka, Lieut. Frederick, exploration in Alaska by.....	341, 342, 380, 400-401
geologic surveys in.....	17-19	Seidmore, E. H., title of paper on Alaska by.....	340
glaciation of.....	35, 156-159	Scotch Creek, Colorado, sections on.....	62, 68-69
gypsum deposits in.....	49, 53, 111	Seasons and climate, Alaska.....	412-414
igneous intrusive rocks of.....	29-32, 79-97	Serebrennikof, exploration in Alaska by.....	400
Juratrias rocks of.....	28-29, 66-77	Sericite, Boulder Hot Springs, Montana, microscopic petrography of.....	253
laccolithic deformation of.....	104-105	Seton-Karr, H. W., Alaskan exploration by.....	341
landslides in.....	129-131, 161	Sheep Creek, Alaska, trails along.....	454
literature concerning.....	17-19	Sheets, intrusive, Rico Mountains, Colorado, occurrence of.....	90
location and nomenclature of.....	15-16	Shorty Creek, Alaska, features of.....	356
ore deposition in.....	33-34	gold prospects on.....	373-374
Permian Carboniferous rocks of.....	27-28, 60-66	Silica, fibrous, Boulder Hot Springs, Montana, microscopic petrography of.....	253
profile sections of.....	102	Silok River, Alaska, features of.....	352
recent geologic history of.....	35-36, 152-165	Silurian rocks, Alaska.....	358, 367, 368, 433, 474-475
solfataric action in.....	33, 92-93	Silver and gold content of veins at Boulder Hot Springs, Montana.....	248-249
stratigraphy of.....	25-29, 37-56	Silver Creek, Colorado, evidences of glaciation on.....	157, 158
structure of.....	21-25, 98-128	faults near.....	44, 122-126
surface wash in.....	161-162	Silver Glance Shaft, Rico Mountains, Colorado, section at.....	52-53
talus in.....	161	Silver Peak Range, Nevada, geologic history of.....	197
timber and timber line in.....	20	view of lake beds at.....	202
volcanic phenomena of.....	32-33	view showing lacustral marls near.....	206
Robert Creek, Alaska, route along.....	454	Skagway, Alaska, rocks near.....	361
view of.....	445	Skolai Mountains, Alaska, features of.....	411
Robertson River, Alaska, features of.....	352	geology of.....	428, 434-435
Rocky Mountains, Alaska, features of.....	463	volcanic rocks of.....	429-430
Rohn, Oscar, acknowledgments to.....	364		
Alaskan exploration by.....	343		
report of reconnaissance of Chitina River and Skolai Mountains, Alaska, by.....	393-440		
Rosenbusch, H., cited on formation of sericite.....	247		
Routes and methods of travel in Alaska, 383-387, 415-418, 433-457			
Russell, I. C., Alaskan exploration by.....	341, 342		
cited on Alaskan geology.....	372		
S.....			
St. Elias Range, Alaska, geologic features of.....	373		
profiles of.....	368		
topographic features of.....	345-346		

	Page.		T.	Page.
Skolai Mountains and Chitina River, Alaska, report of reconnaissance of.....	393-440	Tachatna series of rocks, Alaska, age and correlation of.....		367, 433
Skolai Pass, Alaska, trail over.....	417	Taff, J. A., report on Camden coal field of southwestern Arkansas by.....		313-329
Skwentna series of rocks, Alaska, age and correlation of.....	367, 433	Taff, J. A., and Adams, G. I., paper on geology of Eastern Choctaw coal field, Indian Territory, by.....		257-311
Slate Creek, Alaska, gold on.....	483-485	Tahkin River, features of.....		347-348
Slims River, Alaska, deformation of Pleistocene deposits at mouth of.....	371-372	Tahkandit series of rocks, Alaska, age and correlation of.....		367, 433
Smelter fault, Rico Mountains, Colorado, features of.....	120-122	Talus deposits, Rico Mountains, Colorado.....		161
Snowdrifts, topographic effects of.....	179-185	Tanana Glacier, Alaska, exploration at and near.....		407-408
Solfataric action, Rico Mountains, Colorado.....	32-33, 92-94	geology of region near.....		428, 429
South Park fault, Rico Mountains, Colorado, features of.....	122-123	views of.....		406, 408, 410, 412
Sockrider Peak, Colorado, glacial cirques at.....	156-157	Tanana River, Alaska, copper deposits near.....		381, 382, 437, 438
Spathyema nevadensis, a fossil plant from Nevada, description of.....	211-212	explorations on.....		407-408
figure of.....	222	geology of region near.....		425-429
Spencer, A. C., cited on Devonian rocks in Colorado.....	41	route to.....		338-339, 384-386
Spencer, A. C., and Whitman Cross, paper on geology of Rico Mountains by.....	7-165	Tanana and White rivers, old stream occupying valleys of.....		354-355
Spring deposits, Rico Mountains.....	163-165	Tanana River Basin, Alaska, features of.....		351-352
Spruce Gulch, Rico Mountains, faults near.....	114	Tanana series of rocks, Alaska, age and correlation of.....		367, 433
Spurr, J. E., acknowledgments to.....	399	Tatshenshini River Valley, view in.....		344
Alaskan exploration by.....	342	geology of region near.....		363
cited on Alaskan geology.....	357, 358, 360, 372, 376, 433, 436, 438, 466, 471, 472, 474, 481	Telescope Mountain, Colorado, fault at.....		126-128
cited on bedding faults.....	107	landslide areas at.....		136-137
fossils collected in Nevada by.....	204	view from.....		24
Stanton, T. W., fossils identified by.....	72, 423, 424, 428, 439-440, 448	view of.....		140
Steamboat Springs, Nevada, ore depositions by hot waters at.....	233	Telluride folio of Geologic Atlas of the United States, reference to.....		19
Steiger, George, analyses by.....	93-94, 326	Terra Cotta series of rocks, Alaska, age and correlation of.....		367, 433
Sterlina Creek, Alaska, copper deposits on.....	437	Tertiary rocks, Alaska, occurrence and character of.....		362-363
Stevenson, J. J., survey of Choctaw coal field, Indian Territory, made by.....	264			367, 370, 372, 433, 477, 478
Stilbite, Boulder Hot Springs, Montana.....	243-244	Timber and vegetation, Alaska.....		387, 414, 460-461
Stokes, H. N., analyses by.....	82	Tok River, Alaska, features of.....		352
Stone, G. H., cited on glacial phenomena in Colorado.....	156	Tok sandstone, Alaska, age, character, and correlation of.....		362, 367, 370, 433
Sugarloaf Mountain, Indian Territory, syncline near.....	282	Toklat River, Alaska, features of.....		352
Sulphur, Nevada.....	207-208	Tonsina River, Alaska, trails along.....		415-416
Sulphur Bank, California, ore d position by hot waters at.....	233, 251	Topham, Edwin, Alaskan exploration by.....		341
Sulphur Creek, Colorado, glacial deposits on.....	159	Tordrillo series of rocks, Alaska, age and correlation of.....		367, 443
landslide areas near.....	141-143	Tower, G. W., geologic work in Colorado by.....		16
Sulphur Springs, Rico Mountains, Colorado.....	33	Tozi River, Alaska, route along.....		456
Sunrise series of rocks, Alaska, age and correlation of.....	367, 433	Trails and routes in Alaska.....		383-387, 415-418, 453-457
Sushitna schists, Alaska, age and correlation of.....	367, 433	Tramway Bar, Koyukuk River, Alaska, auriferous gravels at.....		478-479
Swift River, Alaska, trail along.....	454	coal bed at.....		485-486
Syenite-porphry, Rico Mountains, Colorado.....	87	gold at.....		483
		Kenai series at.....		477
		Travel in Alaska, routes and modes of.....		383-387, 415-418, 453-457
		Triassic rocks and fossils, Alaska.....		436-427
				431, 433, 439, 440
		Trotter, Coutts, cited on glaciers.....		185-186

	Page.		Page.
Turkey Creek coal mining district, Indian Territory, operations in.....	298-299	White, David, fossils identified by.....	72, 271
Turkey Creek Mining Company, Indian Territory, operations of.....	298, 304	White River, Carboniferous fossils from basin of.....	359
Turner, H. W., paper on the Esmeralda formation by.....	191-226	gneisses on.....	356-357
Twelve-mile beds, Alaska, age and correlation of.....	367, 433	greenstone schists in.....	358
Tyonek beds, Alaska, age and correlation of.....	367, 433	routes to.....	338-339, 385-386
Tyrell, J. B., Alaskan exploration by... cited on Alaskan geology.....	343 379	White River basin, Alaska, features of.....	350-351
V.		White and Tanana rivers, old stream occupying valleys of.....	354-355
Valdes, Alaska, geology of region near... topography of country near.....	419 408	copper deposits of.....	378-382
Valdes series of rocks, Alaska, age and correlation of.....	367, 433	Wilburton, Indian Territory, geologic structure of beds near.....	288
Van Hise, C. R., acknowledgments to... cited on folding.....	390 436	vertical section showing coal beds at.....	289
cited on origin and age of certain metamorphic rocks of Colorado.....	37	Wilburton coal-mining district, Indian Territory, operations in.....	297-298, 304
Vegetation, Alaska.....	357, 414, 460-461	Williams, H. S., cited on subdivisions of the Carboniferous.....	47
Vein filling at Boulder Hot Springs, Montana, nature of.....	240, 244, 248, 249, 254-255	Williams, William, Alaskan exploration by.....	341
origin of.....	248	Willis, Bailey, acknowledgments to.....	399
Vein formation at Boulder Hot Springs, Montana, paper by W. H. Weed on.....	227-255	Wister coal-mining district, Indian Territory, operations in.....	299-300
Veins. See Mineral veins.		Witherspoon, D. C., surveys in Alaska by.....	449
Vogesites, Rico Mountains, Colorado.....	31-32, 87-88	Witteville coal-mining district, Indian Territory, operations in.....	361
Volcanic phenomena, Rico Mountains.....	32, 33	Witteville coals, Indian Territory, occurrence and character of.....	294, 295
Volcanic rocks, Alaska, occurrence and character of.....	371, 429, 430, 481-482	Wood, C. E. S., Alaskan exploration by.....	340
Volcanic tuff, Alaska, occurrence and character of.....	365-366	Wrangell Mountains, Alaska, features of.....	410-411
Volkmar River, Alaska, features of.....	332	geologic map of.....	404
W.		Wright, G. F., Alaskan exploration by.....	341
Wade Creek, Alaska, gold on.....	376-377	Wyoming, glacial sculpture in.....	167-190
Walcott, C. D., cited on Permian rocks of Western States.....	64, 71	Y.	
Water of Boulder Hot Springs, Montana, alteration of rock by action of.....	245, 247	Yellowstone National Park, mineral vein deposits forming in.....	233
analysis of.....	238	Yentna beds, Alaska, age and correlation of.....	367-433
character of.....	237-238	Young, S. H., Alaskan exploration by.....	340
fracture and vein filling by action of.....	239, 244	Yukon Flats, Alaska, lacustrine silts of... topography and drainage of.....	479 465-466
rock decomposition by.....	244, 245	Yukon Hills, Alaska, features of.....	464
theory of ore deposition by.....	249-252	Yukon Plateau, Alaska, features of.....	346-347, 351, 372
Weed, W. H., paper on mineral vein formation at Boulder Hot Springs, Montana, by.....	227-255	granite of.....	472
Wellesley series of rocks, Alaska, age and character of.....	359, 367, 369, 433	topography and drainage of.....	344, 456
Wells, S. J., Alaskan exploration by.....	341, 342	views of.....	348
West Fork series of rocks, Alaska, character and occurrence of.....	475-476	Yukon River, Alaska, coal beds on.....	485-486
		course of.....	463
		Yukon River Basin, Alaska, topography and drainage of.....	462-464
		Z.	
		Zeolite, Boulder Hot Springs, Montana.....	243-244

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1. Physiographic types, by Henry Gannett. 1898. Folio. Four pages of descriptive text and the following topographic sheets: Fargo (N. Dak.-Minn.), a region in youth; Charleston (W. Va.), a region in maturity; Caldwell (Kans.), a region in old age; Palmyra (Va.), a rejuvenated region; Mount Shasta (Cal.), a young volcanic mountain; Eagle (Wis.), moraines; Sun Prairie (Wis.), drumlins; Donaldsonville (La.), river flood plains; Boothbay (Me.), a fiord coast; Atlantic City (N. J.), a barrier-beach coast. Price 25 cents.
2. Physiographic types, by Henry Gannett. 1900. Folio. Eleven pages of descriptive text and the following topographic sheets: Norfolk (Va.-N. C.), a coast swamp; Marshall (Mo.), a graded river; Lexington (Nebr.), an overloaded stream; Harrisburg (Pa.), Appalachian ridges; Poteau Mountain (Ark.-Ind. T.), Ozark ridges; Marshall (Ark.), Ozark Plateau; West Denver (Colo.), hogbacks; Mount Taylor (N. Mex.), volcanic peaks, plateaus, and necks; Cucamonga (Cal.), alluvial cones; Crater Lake special (Oreg.), a crater. Price 25 cents.
3. Physical geography of the Texas region, by Robert T. Hill. 1900. Folio. Twelve pages of text (including 11 cuts); 5 sheets of special half-tone illustrations; 5 topographic sheets, one showing types of mountains, three showing types of plains and searps, and one showing types of rivers and canyons; and a new map of Texas and parts of adjoining territories. Price 50 cents.

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geologic Atlas of the United States is the final form of publication of the topographic and geologic maps. The atlas is issued in parts, or folios, progressively as the surveys are extended, and is designed ultimately to cover the entire country.

Under the plan adopted the entire area of the country is divided into small rectangular districts (designated *quadrangles*), bounded by certain meridians and parallels. The unit of survey is also the unit of publication, and the maps and descriptions of each rectangular district are issued as a folio of the Geologic Atlas.

Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

Two forms of issue have been adopted, a "library edition" and a "field edition." In both the sheets are bound between heavy paper covers, but the library copies are permanently bound, while the sheets and covers of the field copies are only temporarily wired together.

Under the law a copy of each folio is sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Prepayment is obligatory. The folios ready for distribution are here listed.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston	Montana ..	110°-111°	45°-46°	3,351	25
2	Ringgold	Georgia ..	85°-85° 30'	34° 30'-35°	980	25
3	Placerville	Tennessee ..	120° 30'-121°	38° 30'-39°	932	25
4	Kingston	California ..	84° 30'-85°	35° 30'-36°	969	25
5	Sacramento	Tennessee ..	121°-121° 30'	38° 30'-39°	932	25
6	Chattanooga	Tennessee ..	85°-85° 30'	35°-35° 30'	975	25
7	Pikes Peak	Colorado ..	103°-103° 30'	38° 30'-39°	932	25
8	Sewanee	Tennessee ..	85° 30'-86°	35°-35° 30'	975	25
9	Anthracite-Tested Butte	Colorado ..	106° 45'-107° 15'	38°-43°-39°	465	50
10	Harpers Ferry	West Va. ..	77° 30'-78°	39°-39° 30'	925	25
11	Jackson	Maryland ..	77° 30'-78°	39°-39° 30'	925	25
12	Estillville	California ..	120° 30'-121°	38°-38° 30'	938	25
13	Fredericksburg	Virginia ..	82° 30'-83°	36° 30'-37°	937	25
14	Fredericksburg	Tennessee ..	77°-77° 30'	38°-38° 30'	938	25
15	Staunton	Virginia ..	79°-79° 30'	38°-38° 30'	938	25
16	Tausen Peak	West Va. ..	121°-122°	40°-41°	3,634	25
17	Knoxville	California ..	83° 30'-84°	35° 30'-36°	925	25
18	Marysville	N. Carolina ..	121° 30'-122°	39°-39° 30'	925	25
19	Smartsville	California ..	121°-121° 30'	39°-39° 30'	925	25
20	Stevenson	Alabama ..	85° 30'-86°	31°-31° 30'	980	25
21	Cleveland	Georgia ..	85° 30'-86°	31°-31° 30'	980	25
22	Cleveland	Tennessee ..	84° 30'-85°	35°-35° 30'	975	25
23	Pikeville	Tennessee ..	85°-85° 30'	35° 30'-36°	969	25
24	McMinnville	Tennessee ..	85° 30'-86°	35° 30'-36°	969	25
25	Nomini	Tennessee ..	76° 30'-77°	38°-38° 30'	938	25
26	Three Forks	Virginia ..	76° 30'-77°	38°-38° 30'	938	25
27	London	Montana ..	111°-112°	45°-46°	3,351	50
28	London	Tennessee ..	84°-84° 30'	35° 30'-36°	969	25
29	Peachblow	Virginia ..	81°-81° 30'	37°-37° 30'	951	25
30	Morristown	West Va. ..	80°-80° 30'	36°-36° 30'	963	25
31	Piedmont	Tennessee ..	80°-80° 30'	36°-36° 30'	963	25
32	Piedmont	Maryland ..	79°-79° 30'	36°-36° 30'	925	25
33	Nevada City	West Va. ..	79°-79° 30'	36°-36° 30'	925	25
34	Nevada City	California ..	121° 00'-121° 30'	39° 30'-39° 17' 16"	11.65	50
35	Grass Valley	California ..	121° 01'-121° 05' 01"	39° 10'-39° 13' 50"	12.09	50
36	Banner Hill	California ..	120° 57'-121° 00' 25"	39° 13'-39° 17' 16"	11.65	50
37	Yellowstone National Park	Wyoming ..	110°-111°	44°-45°	3,412	75
38	Yellowstone National Park	Wyoming ..	110°-111°	44°-45°	3,412	75
39	Pyramid Peak	California ..	120°-120° 30'	41°-42°	932	25
40	Franklin	Virginia ..	79°-79° 30'	38° 30'-39°	932	25
41	Brieville	West Va. ..	84°-84° 30'	36°-36° 30'	963	25
42	Buckhannon	Tennessee ..	80°-80° 30'	35°-35° 30'	963	25
43	Gadsden	West Va. ..	80°-80° 30'	35°-35° 30'	963	25
44	Gadsden	Alabama ..	86°-86° 30'	34°-34° 30'	986	25
45	Pueblo	Colorado ..	104° 30'-105°	38°-38° 30'	928	50
46	Downville	California ..	120° 30'-121°	39° 30'-39° 17' 16"	919	25
47	Butte Special	Montana ..	112° 20'-112° 30' 42"	45° 50'-46° 02' 54"	22.80	50
48	Truckee	California ..	120°-120° 30'	39°-39° 30'	925	25
49	Wardburg	Tennessee ..	84° 30'-85°	36°-36° 30'	963	25
50	Sonoma	California ..	120°-120° 30'	37°-37° 30'	944	25
51	Nueces	Texas ..	100°-100° 30'	29°-29° 30'	1,055	25
52	Bidwell Bar	Texas ..	100°-100° 30'	29°-29° 30'	1,055	25
53	Tazewell	California ..	121°-121° 30'	39° 30'-39° 17' 16"	918	25
54	Tazewell	Virginia ..	81° 30'-82°	37°-37° 30'	950	25
55	Boise	West Va. ..	81° 30'-82°	37°-37° 30'	950	25
56	Boise	Idaho ..	116°-116° 30'	43° 30'-44°	864	25
57	Richmond	Kentucky ..	84°-84° 30'	37°-37° 30'	911	25
58	London	Kentucky ..	84°-84° 30'	37°-37° 30'	911	25
59	Tennile District	Colorado ..	106° 8'-106° 16'	38° 22'-38° 30' 30"	55	25
60	Special	Colorado ..	106° 8'-106° 16'	38° 22'-38° 30' 30"	55	25
61	Roseburg	Oregon ..	123°-123° 30'	43°-43° 30'	871	25

out of stock

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area in square miles.	Price, cents.
50	Holyoke	Mass.	72° 30'—73°	42—42° 30'	885	50
51	Big Trees	California	120°—120° 30'	38°—38° 30'	938	25
52	Absaroka: Crandall	Wyoming.	109° 30'—110°	44°—44° 30'	1,706	25
53	Standingstone	Tennessee	85°—85° 30'	36°—36° 30'	963	25
54	Tacoma	Washington.	122°—122° 30'	47°—47° 30'	812	25
55	Fort Benton	Montana .	110°—111°	47°—48°	3,273	25
56	Little Belt Mts.	Montana .	110°—111°	46°—47°	3,295	25
57	Telluride	Colorado .	107° 45'—108°	37° 15'—38°	236	25
58	Elmoro	Colorado .	104°—104° 30'	37°—37° 30'	950	25
59	Bristol	Virginia..	82°—82° 30'	36° 30'—37°	957	25
61	Monterey	Virginia..	79° 30'—80°	38°—38° 30'	938	25
62	Menominee Special.	Michigan.	(a NW.-SE. area, about	22 m. long, 6½ wide)	150	25
64	Mother Lode	California	(a NW.-SE. rectangle,	70 m. long, 6½ wide)	455	50
64	Uvalde	Texas	99° 30'—100°	29°—29° 30'	1,040	25
65	Tintic Special	Utah	111° 55'—112° 10'	39° 45'—40°	229	25

STATISTICAL PAPERS.

Mineral Resources of the United States, 1882, by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

Mineral Resources of the United States, 1889 and 1890, by David T. Day. 1892. 8°. viii, 671 pp. Price 50 cents.

Mineral Resources of the United States, 1891, by David T. Day. 1893. 8°. vii, 630 pp. Price 50 cents.

Mineral Resources of the United States, 1892, by David T. Day. 1893. 8°. vii, 850 pp. Price 50 cents.

Mineral Resources of the United States, 1893, by David T. Day. 1894. 8°. viii, 810 pp. Price 50 cents.

On March 2, 1895, the following provision was included in an act of Congress:

"Provided, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the Director of the Geological Survey."

In compliance with this legislation the following reports have been published:

Mineral Resources of the United States, 1894, David T. Day, Chief of Division. 1895. 8°. xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl. Being Parts III and IV of the Sixteenth Annual Report.

Mineral Resources of the United States, 1895, David T. Day, Chief of Division. 1896. 8°. xxiii, 542 pp., 8 pl. and maps; iii, 543-1058 pp., 9-13 pl. Being Part III (in 2 vols.) of the Seventeenth Annual Report.

Mineral Resources of the United States, 1896, David T. Day, Chief of Division. 1897. 8°. xii, 642 pp., 1 pl.; 643-1400 pp. Being Part V (in 2 vols.) of the Eighteenth Annual Report.

Mineral Resources of the United States, 1897, David T. Day, Chief of Division. 1898. 8°. viii, 651 pp., 11 pl.; viii, 706 pp. Being Part VI (in 2 vols.) of the Nineteenth Annual Report.

Mineral Resources of the United States, 1898, by David T. Day, Chief of Division. 1899. 8°. viii, 616 pp.; ix, 804 pp., 1 pl. Being Part VI (in 2 vols.) of the Twentieth Annual Report.

The money received from the sale of the Survey publications is deposited in the Treasury, and the Secretary of the Treasury declines to receive bank checks, drafts, or postage stamps. All remittances, therefore, must be by MONEY ORDER, made payable to the Director of the United States Geological Survey, or in CURRENCY—the exact amount. Correspondence relating to the publications of the Survey should be addressed to—

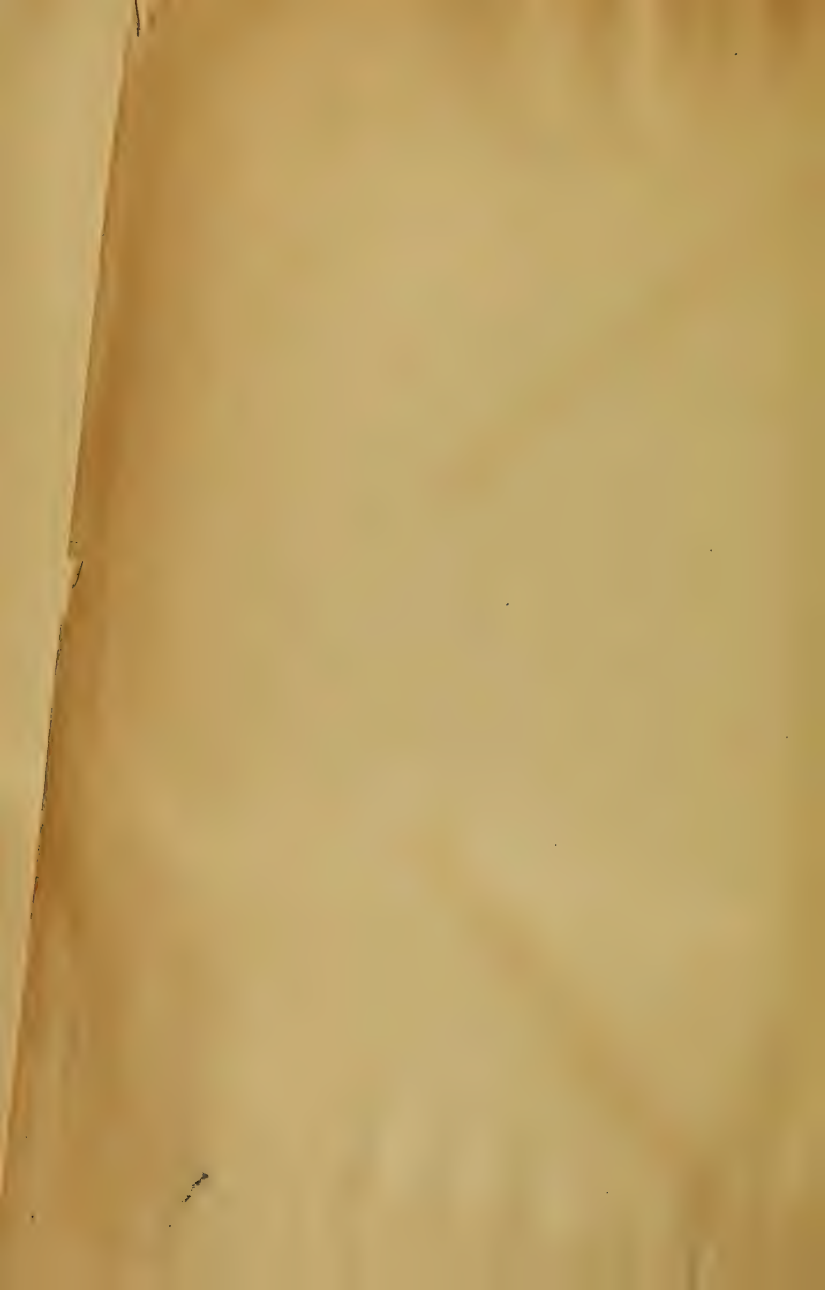
THE DIRECTOR,

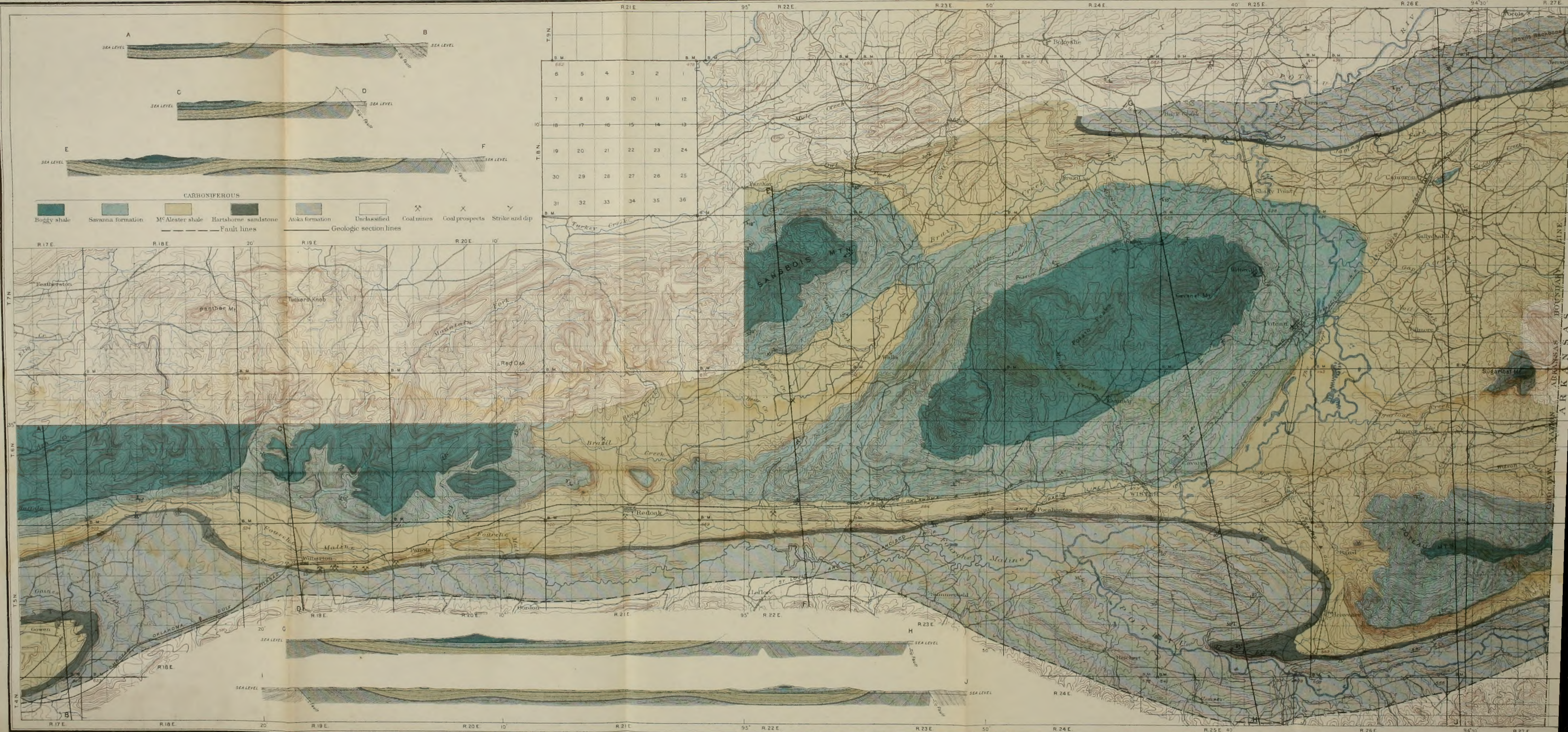
UNITED STATES GEOLOGICAL SURVEY,

WASHINGTON, D. C.

WASHINGTON, D. C., December, 1900.







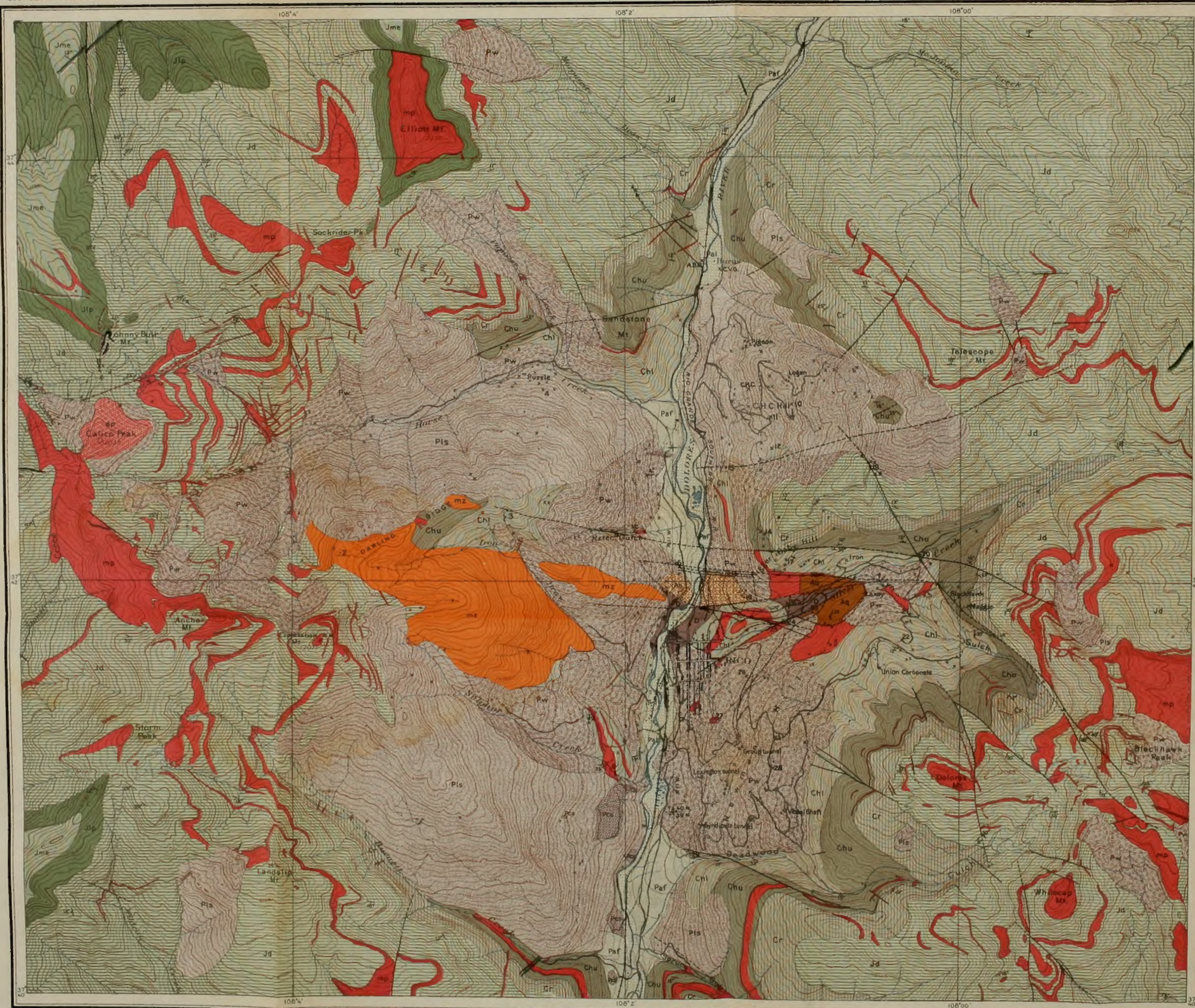
GEOLOGICAL MAP OF PART OF THE EASTERN CHOCTAW COAL FIELD

BY
JOSEPH A. TAFF AND GEORGE LADAMS
1900

Horizontal and vertical scale
Contours Interval 50 feet

LIST OF MINES INDICATED
BY NUMBERS ON MAP

- 1 JOHNNY BULL
- 2 UNCLE REMUS
- 3 ZULU CHIEF
- 4 M. A. C.
- 5 AZTEC
- 6 CALUMET
- 7 MONTEZUMA
- 8 SHAMROCK
- 9 ARONAUT
- 10 WELLINGTON
- 11 PRINCETON
- 12 PREMIER
- 13 CLAN CAMPBELL
- 14 HOPE AND CROSS
- 15 NORA-LILY
- 16 FUTURITY
- 17 NELLIE BLY
- 18 LAST CHANCE
- 19 UNCLE NED
- 20 ARGENTINE
- 21 MEDITERRANEAN
- 22 FOREST
- 23 RICHMOND
- 24 SOUTH PARK
- 25 HIBERNIA
- 26 SKEPTICAL
- 27 NEW YEAR
- 28 ENTERPRISE SHAFT
- 29 STEPHANITE



E. M. Douglas, Geographer in charge
 Triangulation by E. M. Douglas and T. M. Bannon
 Topography by W. M. Beaman
 Surveyed in 1898

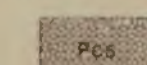
GEOLOGIC MAP OF THE RICO MOUNTAINS, COLORADO

Scale: 1:25,000
 Contour interval: 50 feet
 Distances in miles and feet

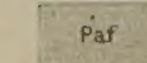
Geology by Whitman Cross and A. C. Spencer
 Surveyed in 1898-99

LEGEND

SURFICIAL FORMATIONS



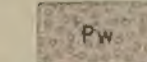
Calcareous tufa



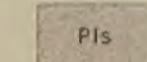
Alluvial fans



Valley alluvium

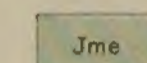


Wash, talus, etc.

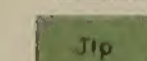


Landslide areas

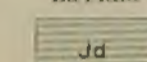
SEDIMENTARY FORMATIONS



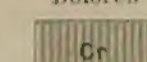
Mc Elmo



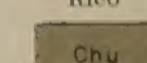
La Plata



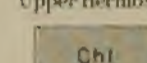
Dolores



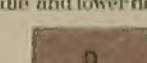
Rico



Upper Hermosa



Middle and lower Hermosa



Limestone and quartzite



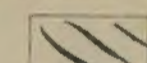
Quartzite

METAMORPHIC FORMATION



Schists

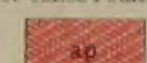
IGNEOUS FORMATIONS



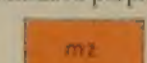
Basic dikes



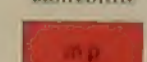
Dikes of Calico Peak porphyry



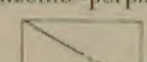
Alumitized porphyry



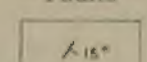
Monzonite



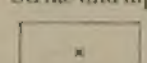
Monzonite-porphyry



Faults



Strike and dip



Mines and prospects



